HOME STUDY COURSE

IN

PRACTICAL ELECTRICITY

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Practical Electricity

AN ELECTRICAL CATECHISM

IN THREE VOLUMES

VOLUME I

PRINCIPLES AND SOURCES OF ELECTRICITY

BY

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PREFACE

The keener competition in engineering, of late years, has forced the need for a more accurate and complete training of those who would succeed in this work. Young men starting in the electrical business without proper training are seriously handicapped, as are also practical workers such as power station men, engineers, electricians and operators of electrical machinery who have not acquired a fundamental knowledge of their work, so that it is no longer a question of choice whether or not they shall thoroughly understand the facts and principles of electricity; it is a matter of necessity.

The purpose of the 1400 Questions and Answers given here is to meet this need by providing a simple and easily mastered course of instruction in practical electricity and the elements of electrical engineering. The contents should also prove useful as a reference guide for those who desire to "brush up" on rusty points and as a source of information for all who have occasion to use electricity in any form.

The author originally prepared these Questions and Answers for the magazine *Power*, in which they were published as an "Electrical Catechism" more or less continuously from January 1, 1905, to July 16, 1912. Owing to the widespread interest in the serial, the author was induced to assemble the material for publication in book form. In doing this, the descriptions and explanations have been carefully revised and simplified to the utmost possible degree consistent with a thorough presentation of the subject, new illustrations prepared especially for the text have been added, and the material as a whole has been brought to date.

Special care has been taken to make the reading matter easily understood, both by clear wording and by reference

letters on the illustrations; also, by introducing new subjects in the proper order for an easy grasp of their relation to the preceding ones. The author takes this opportunity to thank the many electrical manufacturing companies who have so generously coöperated with him in producing the work.

W. H. R.

BROOKLYN, N. Y.
April, 1916.

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LEADING PRINCIPLES

1. **What is electricity?**

Electricity is a form of energy, and is known to us merely by the effects which it produces. As to the constituents of electricity we know practically nothing; but we are equally ignorant of the nature of gravity. Who, for example, can explain why an unsupported body falls toward the ground? To say it does so by reason of the body being heavier or weighing more than the surrounding air is simply reasoning in a circle, for without gravity there would be no weight, and of gravity we know nothing except the effects produced.

Notwithstanding this ignorance of what gravity really is, no one hesitates to place an order for a pile driver through fear that gravity, upon which the driver depends for its operation, will fail to perform its function. Thus it is that, although nothing is known of gravity itself, the effects which it produces are well known and the laws governing its action are perfectly understood.

Similarly with electricity, we know the conditions under which it can be produced, the manner in which it can be controlled and the effects resulting from its use. In short, we know all that is necessary to be known about electricity in order to derive from it the greatest benefit. Nothing would be gained in a commercial way were its constituents also known, so that an insight as to the exact nature of electricity is really immaterial.

2. By what methods may a current of electricity be generated on a commercial scale?

Up to the present time there are but two methods available for the generation of a current of electricity on a commercial scale. Of the two methods, one is by chemical action, and this method is considered practical only for the production of a small current at a moderate pressure. Such currents, however, are very useful in operating electric bells, annun-

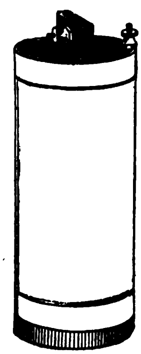


Fig. 1.—Battery Cell.

ciators, burglar alarms and the delicate instruments used in telephony and telegraphy. They are also useful for obtaining electrical measurements, and in most cases of experimental work. When electricity is produced for the purposes just mentioned by chemical action, it is generated in a battery cell, Fig. 1. The manner in which a current of electricity is thus produced will be described in detail when the subject of battery cells is being considered.

The second of the two methods employed for generating a current of electricity on a commercial scale is by magnetic induction; in other words, by cutting magnetic lines of force with a number of closed coils of wire. This is the principle upon which operate the dynamos or electric generators which are to-day flooding with power and light all the civilized countries of the globe. The manner in which the magnetic lines

of force are obtained in an electric generator, Fig. 2, and the arrangement of the coils of wire, are features which will be explained in connection with the description of these machines.

3. **Describe the analogy between the flow of electricity in a wire and the flow of water in a pipe.**

That which forces electricity through a wire is the volts or voltage. It is sometimes called the pressure, the electro-

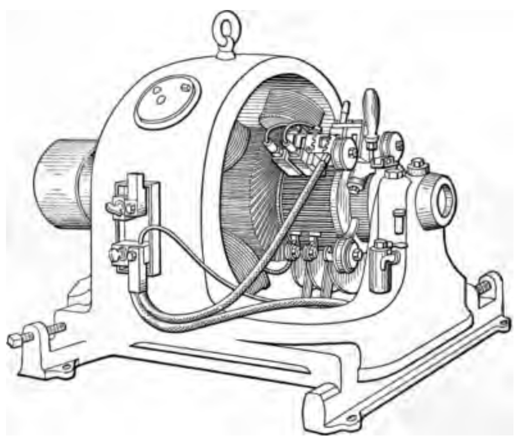


Fig. 2.—Electric Generator.

motive force, the difference in potential, but whichever term is used, it corresponds to the pressure in pounds per square inch that forces water through a pipe.

Compare the two illustrations in Fig. 3, which shows a water system at the left and an electric system at the right. The pump corresponds to the generator, the high level pipe to the positive conductor, the low level pipe to the negative conductor, the water motor to the electric motor, the valve to the switch, and the size of the pipe to the size of the conductor or wire.

Now, just as the pressure of the water in the pipe corresponds to the voltage, so the flow of water in gallons per second

corresponds to the flow of current in amperes. The larger the pipe the less resistance is offered to the flow of water, and the larger the wire conductor the less resistance in ohms is offered to the flow of current.

In comparing the action of electricity with that of water, it must be borne in mind that there is in reality no such thing

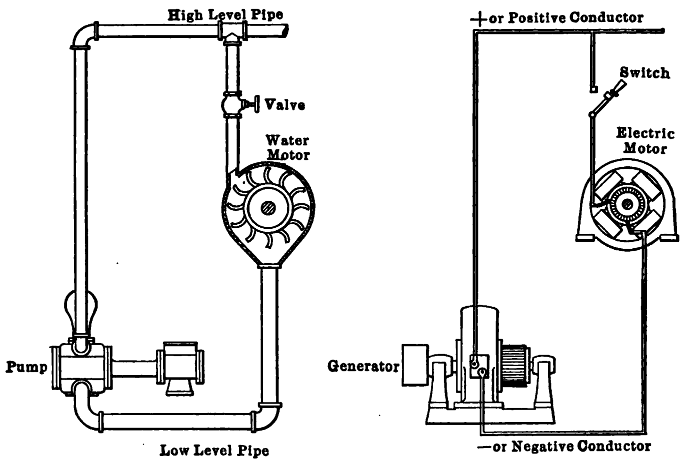


Fig. 3.—Illustrating the Analogy between Electricity and Water, a Water System being shown at the Left and an Electric System at the Right.

as " electric fluid " or " electric juice " and that water has both weight and mass, while electricity has neither. Owing to the similarity in the action of these two forces, however, the comparison is advantageous in impressing the characteristics of electricity upon the mind.

4. What two conditions must be satisfied in order to obtain a current of electricity?

First, there must be a conducting path for the current, and second, there must be a difference of potential between the two extremities of the conducting path, just as in the case of water there must be a difference of pressure between the ends of a pipe in order to force the water through it.

5. What is generally used as the conducting path for a current?

The usual path provided for a current of electricity is of copper wire, copper being chosen because it offers a low resistance per unit of weight, is easily soldered in making joints, and is of a reasonable cost.

It may be mentioned, however, that silver offers still less resistance to a current of electricity than does copper of the same length and area, but is far too expensive to be seriously considered for general use. Aluminum offers about half the resistance per unit of weight shown by copper, but does not possess as high a tensile strength and is not easily soldered. As compared with other metals, the advantages of copper as a conducting path for the current are still more pronounced.

6. Is it impossible to obtain current from any source unless there is a difference of potential between its terminals?

Current cannot be obtained from any source unless there is a difference of potential between its terminals. This difference of potential is the voltage or pressure required to force current through any conducting path or circuit that may be joined to the terminals.

The greater the difference of potential between the extremities of the conducting circuit and the lower the resistance of the circuit, the greater will be the current that will flow through it. On the other hand, the less the difference of potential and the higher the resistance of the circuit, the smaller will be the current.

ELECTRICAL UNITS

7. What is the unit of resistance?

The unit of resistance is the ohm; one ohm is equal to the resistance of a column of pure mercury 106.3 centimeters in height and 0.01 square centimeter in cross-section, at a temperature of 32 degrees Fahrenheit measured at sea level (1 centimeter = 0.3937 inch). The ohm was named after George Simon Ohm, a German electrician who lived from 1787 to 1854.

8. What is the unit of current?

The unit of current is the ampere; one ampere is that current which, when passed through a standard solution of nitrate of silver in water, deposits silver at the rate of 0.001118 gram per second. (1 gram is the weight of a cubic centimeter of water at 39.2 degrees Fahrenheit.) The ampere was named after André Marie Ampère, a French physicist who lived from 1775 to 1836.

9. What is the unit of electromotive force?

The unit of electromotive force is the volt; one volt is the pressure which will force a current of one ampere of electricity through a wire having a resistance of one ohm. This unit was named after Alessandro Volta, an Italian physicist who lived from 1745 to 1827.

10. What is Ohm's law?

A law established by the discoverer of the ohm, and which is as follows: The current strength varies directly as the electromotive force, and inversely as the resistance. In terms of the three fundamental units just explained, the law is: The number of amperes flowing through a circuit equals the number of volts across the circuit divided by the number of ohms in the circuit.

11. What is the usual method of expressing Ohm's law?

In a formula, thus, $I = \frac{E}{R}$, in which I represents the current strength in amperes, E the electromotive force in volts, and R the resistance in ohms.

12. If 120 volts be supplied to a circuit which has a resistance of 20 ohms, what current, according to Ohm's law, will flow through the circuit?

According to the problem the electromotive force $E = 120$ volts, and the resistance $R = 20$ ohms. Substituting these two values for E and R in the formula $I = \frac{E}{R}$, there results $I = \frac{120}{20}$, which gives 6. Six amperes will therefore flow through the circuit.

13. Can Ohm's law be expressed in other forms besides that given in answer to Question 11?

It may be expressed thus, $E = I R$, which by interpretation is: The electromotive force in volts across a circuit equals the current strength in amperes flowing through the circuit multiplied by the resistance of the circuit in ohms.

Another form in which Ohm's law may be expressed is $R = \frac{E}{I}$. This by interpretation reads: The resistance in ohms of a circuit equals the electromotive force in volts across it divided by the current strength in amperes flowing through it.

Both these forms of Ohm's law are obtained from the original equation $I = \frac{E}{R}$, the first form by solving the equation algebraically to obtain E, thus if $I = \frac{E}{R}$, then $I R = E$, or by transposing, $E = I R$. The second form is obtained by solving the equation algebraically to obtain R, thus if $I = \frac{E}{R}$, then $IR = \mathrm{E}$ and from this $R = \frac{E}{I}$.

14. A current of 50 amperes is flowing through a circuit having a resistance of 10 ohms. What voltage, according to Ohm's law, is being supplied to the circuit?

According to the problem the current $I = 50$ amperes, and the resistance $R = 10$ ohms. Substituting these two values for I and R in that form of Ohm's law in which E is expressed in terms of I and R, that is in the form $E = I\,R$, there results $E = 50 \times 10$, which gives 500. Five hundred volts are therefore being supplied to the circuit.

15. What is the resistance of a circuit, according to Ohm's law, if a current of 2 amperes is obtained when the pressure supplied to the circuit is 15 volts?

According to the problem the current $I = 2$ amperes, and the electromotive force $E = 15$ volts. Substituting these two values of I and E in that form of Ohm's law in which R is expressed in terms of I and E, that is in the form $R = \frac{E}{I}$, there results $R = \frac{15}{2}$, which gives 7.5. Seven and one-half ohms is therefore the resistance of the circuit.

16. Why is a thorough understanding of Ohm's law so important in the study of electricity?

It is important for the reason that Ohm's law in its original and derived forms constitutes the basis of most calculations pertaining to electricity. It is obvious from what has already been explained that if any two of the three quantities E, I and R be known, the third can easily be calculated by applying the simple rules of arithmetic.

17. Is the volt the only unit of pressure, and the ampere the only unit of current strength?

They are the only units generally employed for these quantities; in special instances where very small voltages and currents are handled, a smaller unit of pressure called the microvolt is used, and a smaller unit of current called the milliampere is employed. A microvolt is equal to 0.000001 volt, and a milliampere is equal to 0.001 ampere. A pressure of

0.000005 volt would therefore be called 5 microvolts, and a current of 0.002 ampere would be called 2 milliamperes.

18. Is the ohm the only unit of resistance?

It is the only unit generally employed for this quantity. As in the cases of pressure and current, however, there is a smaller unit of resistance called the microhm, employed in special instances. A microhm is equal to 0.000001 ohm. When considering very large resistance, a unit of resistance larger than the ordinary ohm is also used. This unit is called the megohm, and is equal to 1,000,000 ohms. A resistance of 0.000006 ohm would therefore be called 6 microhms, while a resistance of 8,500,000 ohms would be called 8.5 megohms.

19. What unit is used to express a quantity of electricity?

The unit quantity of electricity is the coulomb; one coulomb is the quantity of electricity transferred by a current of one ampere in one second. This unit was named after Charles A. Coulomb, a celebrated physicist who lived from 1736 to 1806.

20. Give the formula that should be used for finding the quantity of electricity passing through a circuit.

The formula is $Q = I\,t$, in which Q represents the quantity of electricity in coulombs, I the current strength in amperes, and t the time in seconds during which the current is flowing.

21. What quantity of electricity will pass through a circuit in 30 seconds if the current therein be 5 amperes?

According to the problem the current $I = 5$ amperes, and the time $t = 30$ seconds. Substituting these two values in the formula $Q = I\,t$, there results $Q = 5 \times 30$, which gives 150. One hundred and fifty coulombs of electricity will therefore pass through the circuit.

22. Is there any other unit for expressing a quantity of electricity?

Yes, there is a larger unit called the ampere-hour.

23. What is an ampere-hour?

One ampere-hour is simply another way of saying 3,600 coulombs, it being 1 ampere multiplied by 1 hour, or 3,600 seconds. One ampere-hour or 3,600 coulombs might mean two amperes for one-half an hour, or one-half an ampere for two hours, as well as one ampere for one hour, since the product of the two factors in any one of these quantities gives one ampere-hour or 3,600 coulombs.

24. What is the unit of electrical power?

The unit of electrical power is the watt; one watt is the amount of power being expended in a circuit in which a current of one ampere is maintained by a pressure of one volt. The watt was named after James Watt, who lived 1736 to 1819.

25. Give the formula to be used for finding the watts expended in a circuit in terms of the current and electromotive force.

The formula is $W = I\,E$, in which W represents the electrical power in watts expended in the circuit, I the current in amperes flowing through the circuit, and E the electromotive force in volts across the circuit.

As in the equation for Ohm's law, if any two of the three quantities W, I and E are known, the third may readily be found, for from $W = I\,E$ may be obtained $I = \frac{W}{E}$ and $E = \frac{W}{I}$.

26. Determine the electrical power expended in a circuit in which 4 amperes is flowing, and the pressure across the circuit is 120 volts.

According to the problem the current $I = 4$ amperes, and the pressure $E = 120$ volts. Substituting these two values in the formula $W = I\,E$, there results $W = 4 \times 120$, which gives 480. Four hundred and eighty watts are therefore being expended in the circuit.

27. Calculate the current in a 250-volt circuit where 750 watts is being expended.

According to the problem the pressure $E = 250$ volts, and the power $W = 750$ watts. Substituting these two values in the formula $I = \frac{W}{E}$, there results $I = \frac{750}{250}$, which gives 3. Three amperes is therefore the current in this circuit.

28. What is the electromotive force of a circuit in which 720 watts is being expended when the current is 6 amperes?

According to the problem the power $W = 720$ watts, and the current $I = 6$ amperes. Substituting these two values in the formula $E = \frac{W}{I}$, there results $E = \frac{720}{6}$, which gives 120. One hundred and twenty volts is therefore the electromotive force of the circuit.

29. Give the formula to be used for finding the watts expended in a circuit in terms of the current and resistance.

The formula is $W = I^2R$, and is obtained by substituting in the original formula, $W = I\ E$, the value of E, which has previously been found equal to $I\ R$. It follows, therefore, that $W = I \times I\ R = I^2R$. The power thus represented is that used in overcoming the resistance R of the circuit, and is consequently termed the resistance loss of the circuit.

30. What is the resistance loss in a circuit of 3 ohms resistance with a current of 4 amperes?

According to the problem the current $I = 4$ amperes, so that $I^2 = 16$ amperes. The resistance $R = 3$ ohms. Substituting these two values in the formula $W = I^2R$, there results $W = 16 \times 3 = 48$. Forty-eight watts therefore represents the resistance loss in this circuit.

31. Is the watt the only unit of electrical power?

No, a larger unit called the kilowatt is often used; one kilowatt equals 1,000 watts.

32. What relation is there between watts and horsepower?

One horsepower equals 746 watts. Accordingly, 5 horsepower $= 5 \times 746$, or 3,730 watts, which may also be called 3.73 kilowatts.

33. Is there a unit for the electrical energy produced by electrical power operating for a given time?

Yes; the unit of electrical energy is the watt-hour. One watt-hour is the energy represented by one watt operating for one hour. The same amount of energy would result from one-half a watt operating for two hours, or from two watts operating for one-half an hour. In like manner, 10 watt-hours might mean five watts for two hours, or two watts for five hours, or ten watts for one hour.

34. Is there a kilowatt-hour?

Yes; it is the energy represented by one kilowatt operating for one hour.

35. Is there a unit for expressing the work done in a circuit by a current flowing through it?

Yes; this unit is the joule. One joule is the energy expended in one second by one ampere flowing through a resistance of one ohm.

36. What unit is used for expressing the capacity of a condenser or other body charged with electricity?

The unit of condenser or electrostatic capacity is the farad; one farad is the capacity of a body charged to a potential of one volt by one coulomb of electricity.

The farad, although in reality the unit of capacity, is so large that it exists only in imagination, the capacity of the earth being only about 0.0007 farad, and that of the sun 0.076 farad. The practical unit, therefore, is the microfarad, which is one-millionth of a farad.

37. What is the unit of electromagnetic induction?

The henry; one henry is the induction in a circuit where one volt is induced by an inducing current which varies at the rate of one ampere per second.

As the henry is so large as to be seldom met with in practice, one-thousandth of it, called the millihenry, is the induction unit most in use.

38. What types of thermometers are in use for measuring temperatures in electrical engineering work?

The Fahrenheit thermometer, in which there are 180 equal divisions on the scale between the freezing and boiling points of water; and the Centigrade thermometer, in which there are 100 equal divisions on the scale between the freezing and boiling points of water.

39. How may a reading on the Fahrenheit scale be converted into Centigrade measure?

By subtracting 32 and multiplying by $\frac{5}{9}$. Thus with 68 degrees Fahrenheit, $68 - 32 = 36$, and $36 \times \frac{5}{9} = 20$ degrees Centigrade.

40. How may a reading on the Centigrade scale be converted into Fahrenheit measure?

By multiplying by $\frac{9}{5}$ and adding 32. Thus with 30 degrees Centigrade, $30 \times \frac{9}{5} = 54$, and $54 + 32 = 86$ degrees Fahrenheit.

CONDUCTORS AND INSULATORS

41. What is a conductor?

Any substance that offers only a slight resistance to the passage of an electric current. Theoretically, there is no substance that is a perfect conductor; that is, there is none that is entirely without resistance. In general, good conductors of heat are also good conductors of electricity.

42. How are conductors rated?

With respect to their conductivity or capability of conducting an electric current. Conductivity is the reciprocal of resistance. If, therefore, a substance has a resistance of 4 ohms, and another substance has a resistance of 8 ohms, their respective conductivities are $\frac{1}{4}$ and $\frac{1}{8}$; in other words, the conductivity of the former substance is twice that of the latter substance.

43. Give a list of conductors in the order of decreasing conductivities.

Silver, copper, gold, aluminum, zinc, platinum, iron, tin, lead, German-silver, mercury, charcoal, acids, water.

44. What is an insulator?

Any substance that offers much resistance to the passage of an electric current. Theoretically, there is no substance that is a perfect insulator; that is, there is none that offers so great a resistance as to entirely obstruct the passage of a current of electricity. In general, poor conductors of heat are insulators.

45. Give a list of insulators in the order of decreasing conductivities.

Oils, porcelain, wool, silk, resin, gutta-percha, shellac, ebonite, paraffin, glass, dry air.

46. How are different insulators compared with respect to their resistance?

By stating their specific resistances, that is the resistance between opposite faces of a cube of the substance measuring one centimeter on a side.

47. Knowing the specific resistance of substances, can their relative conductivities be calculated?

Yes. For example, if the specific resistance of silver be 1.521 microhms and that of mercury be 99.74 microhms, then if the conductivity of mercury be taken as unity or 1, the relative conductivity of silver will be $99.74 \div 1.521 = 66$ approximately. That is, silver is 66 times as good a conductor as is mercury.

48. Give a table showing the specific resistances and the relative conductivities of the metals mentioned in Answer 43.

Substance	Specific Resistance in Microhms at 0 Degrees Centigrade	Approximate Relative Conductivity (Mercury Unity)
Silver	1.521	66.
Copper	1.616	62.
Gold	2.081	48.
Aluminum	2.945	34.
Zinc	5.689	18.
Platinum	9.158	11.
Iron	9.825	10.
Tin	13.36	7.5
Lead	19.85	5.0
German-silver	21.17	4.7
Mercury	99.74	1.0

49. Upon what factors does the resistance of a substance depend?

Its length, cross-sectional area and specific resistance. The resistance of a substance increases directly as its length and inversely as its cross-sectional area. Knowing this, and the specific resistance of the material composing the substance from the table given in Answer 48, the resistance of any length and size of conductor at 0 degrees Centigrade can be calculated.

50. Does change of temperature affect the resistance of a substance?

Yes, with metal conductors, each degree Centigrade rise in temperature causes an increase of about four-tenths of one per cent. in their respective resistances. Carbon, acids and a few alloys, however, decrease in resistance with a rise in temperature.

CALCULATION OF RESISTANCE

51. Calculate the longitudinal resistance at 0 degrees Centigrade of a bar of aluminum 2 centimeters in length and 1/2 square centimeter in cross-section.

According to the table in Answer 48, the resistance at 0 degrees Centigrade of a bar of aluminum 1 centimeter in length and 1 square centimenter in cross-section, is 2.945 microhms. Since it is stated in Answer 49 that the resistance of a substance increases directly as its length, an aluminum bar 2 centimeters long would have a resistance of $2 \times 2.945 = 5.89$ microhms if its cross-section was 1 square centimeter. It is also stated in Answer 49 that the resistance of a substance increases inversely as its cross-sectional area, so that if this dimension be $\frac{1}{2}$ square centimeter instead of 1 square centimeter, the resistance longitudinally or along the length of the specified aluminum bar will be 2×5.89 microhms, which is 11.78 microhms or 0.00001178 ohm.

52. What is the longitudinal resistance at 0 degrees Centigrade of a copper bar 6 inches long and 2 square inches in cross-section?

According to the table in Answer 48, the resistance at 0 degrees Centigrade of a bar of copper 1 centimeter or 0.3937 inch in length, and 1 square centimeter or 0.155 square inch in cross-section, is 1.616 microhms. Applying the principles given in the preceding case to the one now in hand, it follows that if the copper bar was 1 inch long it would have a resistance of $\frac{1}{0.3937}$ of 1.616 microhms, but being 6 inches long it has a resistance of $\frac{6}{0.3937}$ of 1.616 microhms $= 24.628$ microhms if its cross-section is 0.155 square inch. If its cross-section was 1 square inch instead of 0.155 square inch, the

longitudinal resistance of the specified copper bar would be 0.155 × 24.628 microhms, but being 2 square inches in cross-section its longitudinal resistance is ½ of 0.155 × 24.628 microhms, which is 1.909 microhms or 0.000001909 ohm.

53. Calculate the longitudinal resistance at 30 degrees Centigrade of a copper bar 6 inches long and 2 square inches in cross-section.

It is obvious that, since the dimensions of this copper bar are the same as in the preceding case, its resistance at 0 degrees Centigrade will be the same, and therefore equal to 1.909 microhms. To find its resistance at 30 degrees Centigrade, the principles given in Answer 50 must be applied. It is there stated that each degree Centigrade rise in temperature causes an increase in resistance of about four-tenths of one per cent., that is, an increase of 0.004. For the 30 degrees Centigrade rise in temperature of the present case, the resistance of 1.909 microhms will be increased 0.004 × 30 = 0.12. That is, 1.909 × 1.12 = 2.138 microhms or 0.000002138 ohm will be the longitudinal resistance of the specified copper bar at 30 degrees Centigrade.

54. How may the resistance of a wire be determined from the table of specific resistances previously given?

By first measuring the diameter of the wire with a micrometer; next, squaring the diameter thus found and multiplying it by 0.7854, for its cross-sectional area; and then, with the given length of the wire and its cross-section just determined, calculating its resistance as in the preceding cases.

55. Is there an easier method of finding the resistance of a wire?

An easier method would be to determine its size by means of a wire gage, and then from a wiring table find the resistance per unit length of wire corresponding to this size. If the resistance thus found be multiplied by the length of the wire expressed in the same units, the result will be the required resistance.

56. Give a table showing the dimensions, carrying capacities and resistances of copper wire.

See table on pages 20 and 21.

57. Explain what is meant by "Gage No. — B. & S." in the first column of the wiring table on pages 20 and 21.

This signifies the wire gage, or measure, in common use at the present time. It is called the Brown & Sharpe gage, al-

Fig. 4.—B. & S. American Standard Wire Gage for Copper Wire. Exact Size.

though the same measure is also known as the American Standard Wire Gage.

In practice, a metal disk cut as shown in Fig. 4 comprises the American Standard Wire Gage. To determine the size of a copper wire, by means of it, the wire is tried in the different slots cut around the outer edge until the slot is found in which the wire fits snugly. The number on the gage corresponding to that slot is the B. & S. gage number of the wire. As Fig. 4 gives the exact size of the gage, the reader can form an accurate idea of the different sizes of copper wire from 5 to 36, the diameter of the wire being the width measured between the straight sides of the slot.

ELECTRICAL PROPERTIES OF COPPER WIRE

Gage No. B. & S.	Diam. Mils.	Area Circular Mils.	BARE WIRE. Feet per Pound.	Lbs. per 1000 ft.	Lbs. per. Mile.	UNDERWRITERS' WIRE. Feet per Pound.	Lbs. per 1000 ft.	Lbs. per Mile.	SAFE CARRYING CAPACITIES. (Cur. in Amps.) Rubber Insulation.	Other Insulations.	RESISTANCES AT 75° FAHRENHEIT (23.9° CENTIGRADE). Ohms per Pound.	Ohms per 1000 ft.	Ohms per Mile.	Feet per Ohm.
0000	460.000	211600.0	1.56	640.73	3383.04	1.25	800	4224	225	325	.0000765	.04904	.25891	20392.9
000	409.640	167805.0	1.97	508.12	2682.85	1.50	666	3516	175	275	.000122	.06184	.32649	16172.1
00	364.800	133079.0	2.48	402.97	2127.66	2.00	500	2640	150	225	.000194	.07797	.41168	12825.4
0	324.950	105592.5	3.13	319.74	1688.20	2.75	363	1917	125	200	.000307	.09827	.51885	10176.4
1	289.300	83694.5	3.95	253.43	1338.10	3.20	313	1653	100	150	.000489	.12398	.65460	8066.0
2	257.630	66373.2	4.98	200.98	1061.17	4.00	250	1320	90	125	.000778	.15633	.82543	6396.7
3	229.420	52633.5	6.28	159.38	841.50	5.00	200	1056	80	100	.00124	.19714	1.04090	5072.5
4	204.310	41742.6	7.91	126.40	667.38	6.9	144	760	70	90	.00197	.24858	1.31248	4022.9
5	181.940	33102.2	9.98	100.23	529.23	8.0	125	660	55	80	.00313	.31346	1.65507	3190.2
6	162.020	26250.5	12.58	79.49	419.69	9.5	105	554	50	70	.00497	.39528	2.08706	2529.9
7	144.280	20816.7	15.86	63.03	332.82	11.5	87	364			.00791	.49845	2.63184	2006.2
8	128.490	16509.7	20.00	49.99	263.96	14.5	69	301	35	50	.0126	.62849	3.31843	1591.1
9	114.430	13094.2	25.22	39.65	209.35						.0200	.79242	4.18400	1262.0
10	101.890	10381.6	31.81	31.44	165.98	20.0	50	264	25	30	.0317	.99948	5.27726	1000.5
11	90.742	8234.11	40.11	24.93	131.65						.0505	1.2602	6.65357	793.56
12	80.808	6529.94	50.58	19.77	104.40	32.0	31	164	20	25	.0804	1.5890	8.39001	629.32
13	71.961	5178.39	63.78	15.68	82.792						.128	2.0037	10.5798	499.06
14	64.084	4106.76	80.42	12.44	65.658	45.0	22	116	15	20	.203	2.5266	13.3405	395.79
15	57.068	3256.76	101.40	9.86	52.069						.323	3.1860	16.8223	313.87

Continuation of this table on following page.

Gage No. B. & S.	Diam. Mils.	Area Circular Mils.	BARE WIRE.			UNDERWRITERS' WIRE.			SAFE CARRYING CAPACITIES. (Cur. in Amps.)		RESISTANCES AT 75° FAHRENHEIT (23.9° CENTIGRADE).			
			Feet per Pound.	Lbs. per 1000 ft.	Lbs. per Mile.	Feet per Pound.	Lbs. per 1000 ft.	Lbs. per Mile.	Rubber Insulation.	Other Insulations.	Ohms per Pound.	Ohms per 1000 ft.	Ohms per Mile.	Feet per Ohm.
16	50.820	2582.67	127.87	7.82	41.292	70.0	14	74	6	10	.514	4.0176	21.2130	248.90
17	45.257	2048.20	161.24	6.20	32.746						.817	5.0660	26.7485	197.39
18	40.303	1624.33	203.31	4.92	25.970	90.0	11	58	3	5	1.299	6.3880	33.7285	156.54
19	35.890	1288.09	256.39	3.90	20.594						2.065	8.0555	42.5329	124.14
20	31.961	1021.44	323.32	3.09	16.331						3.284	10.1584	53.6362	98.44
21	28.462	810.09	407.67	2.45	12.952						5.222	12.8088	67.6302	78.07
22	25.347	642.47	514.03	1.95	10.272						8.302	16.1504	85.2743	61.92
23	22.571	509.45	648.25	1.54	8.1450						13.203	20.3674	107.540	49.10
24	20.100	404.01	817.43	1.22	6.4593						20.994	25.6830	135.606	38.94
25	17.900	320.41	1030.71	.97	5.1227						33.378	32.3833	170.984	30.88
26	15.940	254.08	1299.77	.77	4.0623						53.079	40.8377	215.623	24.49
27	14.195	201.50	1638.97	.61	3.2215						84.399	51.4952	271.895	19.42
28	12.641	159.80	2066.71	.48	2.5548						134.201	64.9344	342.854	15.40
29	11.257	126.72	2606.13	.38	2.0260						213.397	81.8827	432.341	12.21
30	10.025	100.50	3286.04	.30	1.6068						339.267	103.245	545.133	9.686
31	8.928	79.71	4143.18	.24	1.2744						539.340	130.176	687.327	7.682
32	7.950	63.20	5225.26	.19	1.0105						857.850	164.174	866.837	6.091
33	7.080	50.13	6588.33	.15	.8014						1363.786	207.000	1092.96	4.831
34	6.304	39.74	8310.17	.12	.6354						2169.776	261.099	1378.60	3.830
35	5.614	31.52	10478.46	.10	.5039						3449.770	329.225	1738.31	3.037
36	5.000	25.00	13209.98	.08	.3997						5482.766	415.047	2191.45	2.409
37	4.453	19.83	16654.70	.06	.3170						8715.030	523.278	2762.91	1.911
38	3.965	15.72	21006.60	.05	.2513						13864.510	660.011	3484.86	1.515
39	3.531	12.47	26487.84	.04	.1993						22043.920	832.228	4394.16	1.202
40	3.144	9.88	33410.05	.03	.1580						35071.110	1049.718	5542.51	.9526

58. What is a mil?

A mil is one-thousandth of an inch.

59. What is a circular mil?

A circular mil (c.m.) is the unit of area when considering the cross-section of a wire: it is the area of a circle having a diameter of one mil and is therefore equal to 0.7854 square mil, or in terms of a square inch one circular mil equals $0.7854 \times (0.001)^2$ or 0.0000007854 square inch. From this it follows that 1,000,000 circular mils is equal to the area of a circle one inch in diameter, or 0.7854 square inch.

According to the definition of a circular mil given above, the area of a wire in circular mils is found by squaring its diameter in mils; hence the figures in the third column of the wiring table on pages 20 and 21 are the squares of the figures in the second column for the same size or gage of wire.

60. What is meant by "Underwriters' wire"?

Insulated wire approved by the Board of Fire Underwriters. By "insulated wire" is generally meant copper wire covered with a non-conducting material such as silk, cotton or rubber to prevent loss or leakage of current through short circuits. Every electric current has a tendency to return to its starting or exciting point by the shortest route, and the object of the insulation is to make it go by a longer route and enable it to do some work on the way. The "short circuit" is a leap to the earth or some other conductor by which the current's journey is shortened.

61. What is meant in the wiring table by the safe carrying capacity of wire?

The current that can be transmitted by insulated wire without excessive heating.

62. What is the distinction between "Rubber Insulation" and "Other Insulations"?

"Rubber Insulation" refers to wires insulated with rubber compounds. "Other Insulations" refer to wires insulated with weatherproof slow-burning compounds. The

former is used exclusively for all interior wiring, and the latter for outdoor work.

63. Give some simple rules that may aid in remembering the wiring table given on pages 20 and 21.

Bear in mind the dimensions, carrying capacities and resistance of the No. 10 wire. This size of wire has a diameter of approximately 0.1 inch, averages 31 feet per pound, has a safe current carrying capacity of 25 amperes if it has a covering of rubber insulation, and offers a resistance of 1 ohm per 1,000 feet. As the gage numbers decrease from this point the diameters increase about 0.01 inch per number, and as the gage numbers increase the diameters decrease in about the same proportion. The area in circular mils for any gage number is the square of its diameter thus found. The feet per pound are halved every third decreasing number, and doubled every third increasing number. The current carrying capacity is doubled every fourth decreasing number, and halved every fourth increasing number. The ohms per 1,000 feet are halved every third decreasing number, and doubled every third increasing number.

64. Express the diameter of No. 1 copper wire, B. and S. gage, in terms of a foot.

According to the table on page 20, the diameter of No. 1 copper wire is 289.3 mils. Since 1 mil $=$ 0.001 inch, 289.3 mils will be 289.3×0.001 inch $= 0.2893$ inch or 0.0241 foot.

65. Calculate the number of feet in a coil of No. 4 bare copper wire weighing 632 pounds.

Turning to the table on page 20, it is seen that No. 4 bare copper wire weighs 126.4 pounds per 1,000 feet, which is 0.1264 pound per foot. In 632 pounds of this wire there would therefore be $632 \div 0.1264 = 5{,}000$ feet.

66. What resistance has 4 miles of No. 0 B. & S. copper wire at 23.9 degrees Centigrade?

According to the table on page 20, the resistance per mile at 23.9 degrees Centigrade, of No. 0 copper wire is 0.51885

ohm. For 4 miles the resistance would consequently amount to $4 \times 0.51885 = 2.075$ ohms.

67. Find the resistance at 40 degrees Centigrade of 500 feet of copper wire having a diameter of 80.808 mils.

Consulting the table on page 20, No. 12 wire has a diameter of 80.808 mils. The resistance at 23.9 degrees Centigrade of this wire is 1.589 ohms per 1,000 feet, which is 0.001589 ohm per foot. For 500 feet, the resistance at this temperature would therefore be $500 \times 0.001589 = 0.795$ ohm. Between 23.9 degrees and 40 degrees there is a difference or rise of 16.1 degrees. According to Answer 50, each degree Centigrade rise in temperature causes an increase in the resistance of metal conductors, of about four-tenths of one per cent. For 16.1 degrees rise there will consequently be an increase of $16.1 \times 0.004 = 0.0644$. That is, 1.0644×0.795 ohm $=$ 0.846 ohm, which therefore represents the required resistance.

68. Determine the resistance at 75 degrees Fahrenheit of 6 miles of copper wire having an area of 133,079 circular mils.

According to the table on page 20, No. 00 wire has an area of 133,079 circular mils, and this wire has a resistance at 75 degrees Fahrenheit, of 0.41168 ohm per mile. For 5 miles the resistance at this temperature would be 5×0.41168 ohm $= 2.0584$ ohms.

69. A coil of bare copper wire weighing 173 pounds has a resistance of 3.46 ohms. Calculate the size of wire composing this coil.

The resistance per pound of this coil is $3.46 \div 173 = 0.02$ ohm, and from the table on page 20 this resistance represents the number of ohms per pound of No. 9 wire.

70. What size of insulated copper wire should be used for carrying currents up to 12 amperes?

According to the table on page 20, No. 14 B. & S. copper wire would be the proper size.

71. Give a formula showing the relation between the area of a wire, its length, the current to be transmitted, and the desired drop in voltage due to the resistance of the wire.

Let $c.\ m.$ = the area in circular mils,
l = the length of wire in feet,
C = the current in amperes,
v = the drop in voltage, and
10.8 = the ohmic resistance per foot of copper wire 1 mil in diameter at 75 degrees Fahrenheit,

$$\text{Then } c.\ m. = \frac{l \times C \times 10.8}{v}.$$

72. At 100 volts pressure, what size wire will be necessary to carry 25 amperes a distance of 200 feet with a 2 per cent. drop?

A 2 per cent. drop in the present case is $100 \times 0.02 = 2$ volts. Substituting, now, the known values in the formula

$$c.\ m. = \frac{l \times C \times 10.8}{v},$$

there results

$$c.\ m. = \frac{200 \times 25 \times 10.8}{2} = 27{,}000.$$

Referring to the table, it is seen 27,000 c. m. lies between No. 6 wire, which has an area of 26,250.5 c. m., and No. 5 wire, which has an area of 33,102.2 c. m. In such a case, the larger size wire must be chosen, which is No. 5, and as 25 amperes is well within the safe carrying capacity of this conductor it may properly be used.

73. What distance on No. 12 B. & S. copper wire can 15 amperes be transmitted at a pressure of 110 volts with 1.5 per cent. drop?

Transposing the formula given in Answer 71 so as to obtain an expression for the length in feet l in terms of the other quantities, there results $l = \frac{v \times c.\ m.}{C \times 10.8}$. No. 12 B. & S. copper wire, according to the table on page 20, has an area of 6529.94 circular mils. The actual drop v is $110 \times 0.015 =$

1.65 volts. Substituting, now, the known values in the right-hand side of the new equation, it follows that

$$l = \frac{1.65 \times 6529.94}{15 \times 10.8},$$

which gives 66.5 feet. The permissible distance is, therefore, 66 feet 6 inches.

74. Calculate the current at 220 volts that can be carried 300 feet on a copper conductor having an area of 26,250.5 c. m., with a drop not exceeding 4 volts.

Transposing the formula given in Answer 71 so as to obtain an expression for the current in amperes C in terms of the other quantities, there results $C = \frac{v \times c.\ m.}{l \times 10.8}$. Substituting the given values in the right-hand side of this equation, it follows

$$C = \frac{4 \times 26{,}250.5}{300 \times 10.8},$$

which gives 32.1 amperes. As this current is well within the safe carrying capacity of the specified conductor, it may properly be transmitted thereby.

75. Find the drop along a No. 000 B. & S. copper wire 1 mile in length when carrying a current of 25 amperes at a pressure of 500 volts.

Transposing the formula given in Answer 71 so as to obtain an expression for the drop in voltage v in terms of the other quantities, there results $v = \frac{l \times C \times 10.8}{c.\ m.}$. No. 000 B. & S. copper wire, according to the table, page 20, has an area of 167,805 circular mils. The 1 mile = 5,280 feet. Substituting, now, the known values in the right-hand side of the new equation, it follows that $v = \frac{5280 \times 25 \times 10.8}{167{,}805}$, which gives 8.5 volts for the drop.

ELECTRICAL CIRCUITS

76. Are there different kinds of electrical circuits?

Yes, there is a series circuit, a parallel circuit, a series-parallel circuit and a compound series-parallel circuit.

77. What is a series circuit?

A series circuit is one consisting of several resistances joined together one after the other so that the same current passes through each of them in succession. A series circuit is illustrated at *A* in Fig. 5, where *a, d* and *c* represent three resistances which might, for example, be the filaments of three incandescent lamps, *b* a battery cell for furnishing current, and *k* a key for opening and closing the circuit. These five parts are joined together by the connecting wires *m, n, s,* etc., and are in series with each other.

When the key *k* is open as in the illustration, no current passes through these five parts of the circuit, but the electromotive force developed in the battery cell is on the circuit and will cause a current to flow when the key is closed. The current in amperes that will pass through the entire circuit will, according to Ohm's law, equal the electromotive force in volts developed in the battery cell, divided by the total resistance in ohms of the several parts of the circuit.

These several parts are on open circuit if the key *k* is open, on closed circuit if the key *k* is closed, and short-circuited if the key *k* is closed and a conductor is made to join the wires leading directly from the battery cell.

78. What current will flow through the series circuit, A, Fig. 5, if the electromotive force of the battery cell b be 2 volts, its resistance 0.25 ohm, the resistance of k 0.05 ohm, the resistance of a 1 ohm, the resistance of d 1.7 ohms,

the resistance of c 1 ohm, and the resistance of the connecting wire be negligible?

According to Ohm's law $I = \frac{E}{R}$; that is,

$$I = \frac{2}{0.25 + 0.05 + 1 + 1.7 + 1},$$

which gives 0.5. The current flowing through this series circuit when the key is closed would therefore be 0.5 ampere.

79. Mention the more common applications of the series connection to commercial purposes.

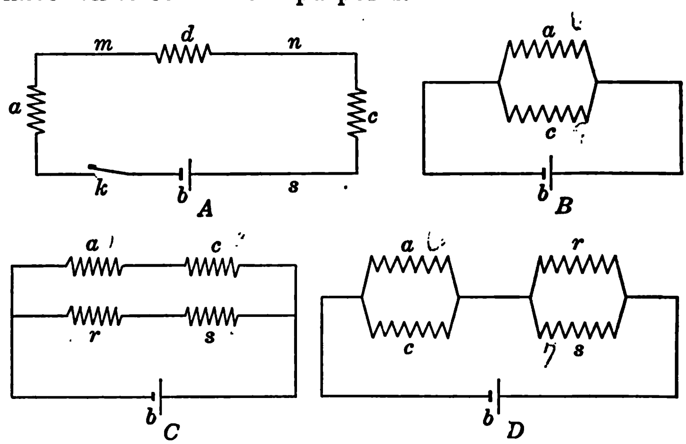


Fig. 5.—Different Forms of Electrical Circuits.

In electric railway work, where the armature windings of the car motors are connected in series with their respective field windings; in direct current arc lighting, where the lamps are joined in series with each other and with the generator; in telegraphy, where batteries, keys, sounders, relays, line wires and ground returns are connected in series.

80. What is a parallel circuit?

A parallel circuit is one composed of two or more branches so that the current is divided among them, the amount of current flowing in any one branch depending upon its resistance relatively to that of the others. A parallel circuit is

illustrated at *B* in Fig. 5 by the manner in which the two resistances *a* and *c* are connected with each other.

If the resistance *a* is equal to the resistance *c*, current from the battery cell *b* will divide equally between *a* and *c*. If, however, these two resistances are not equal, the current will divide inversely to their resistances.

A parallel circuit is also known as a multiple circuit, a divided circuit, or a branched circuit, and the parts composing the same are referred to as being connected, in multiple, in shunt, or in parallel.

81. What current will flow through the parallel circuit B, Fig. 5, if the electromotive force of the battery cell b be 2 volts, the resistance of a 6 ohms, the resistance of c 8 ohms, and the resistance of the battery cell and connecting wires be negligible?

It is first necessary to find the combined or joint resistance of the parallel circuit. This is best determined by considering the conductivity which, according to Answer 42, is the reciprocal of the resistance. The resistance is also equal to the reciprocal of the conductivity. The conductivity of the parallel circuit as a whole is the sum of the conductivities of the separate parts; therefore, the resistance of the circuit as a whole is the reciprocal of the sum of the reciprocals of the resistances of the separate parts. The joint resistance is thus equal to

$$\frac{1}{\text{joint conductivity}}$$

and this, in turn, equals

$$\frac{1}{\text{conductivity of } a + \text{conductivity of } c}.$$

Substituting in this last expression, 1/6 for the conductivity of *a*, and 1/8 for the conductivity of *c*, the fraction becomes

$$\frac{1}{\frac{1}{6}+\frac{1}{8}},$$

which resolves itself into $\dfrac{1}{\frac{7}{24}}$ or $\dfrac{24}{7}$. The joint resistance of

the parallel circuit is, consequently, $\frac{24}{7}$ or 3.4 ohms, and the current flowing through the circuit as a whole is $\frac{2}{3.4} = 0.6$ ampere.

82. If in the parallel circuit B, Fig. 5, 0.6 ampere be flowing through the circuit as a whole, what part of it is flowing through the resistance a, and what part through the resistance c?

Since the resistance of a is 6 ohms, and the resistance of c is 8 ohms, 8/14 of 0.6 ampere $= 0.34$ ampere will flow through a, and 6/14 of 0.6 ampere $= 0.26$ ampere will flow through c.

83. Mention the more common applications of the parallel connection to commercial purposes.

In electric lighting, where incandescent lamps are wired in parallel with each other; also in shunt generators, where the armature windings and field windings are connected in parallel.

84. What is a series-parallel circuit?

A series-parallel circuit is one consisting of two or more series circuits in parallel with each other as at C in Fig. 5. Here the resistances a and c in series with each other, are connected in parallel with the resistances r and s, which are also in series with each other. This series-parallel circuit is supplied with current by the battery b.

The calculations for the joint resistance, the total current and the currents in the branches of the circuit are simple applications of the principles employed in Answers 78, 81 and 82.

85. Mention the more common applications of the series-parallel connection to commercial purposes.

In electric lighting, both for car illumination and for street lighting, incandescent lamps are wired on the series-parallel combination.

86. What is a compound series-parallel circuit?

A compound series-parallel circuit is one consisting of two or more parallel circuits in series as at *D*, Fig. 5, where the resistances *a* and *c* in parallel are connected in series with the resistances *r* and *s* in parallel.

The calculations for the joint resistance, the total current and the currents in the branches of the circuit are simple applications of the principles employed in Answers 78, 81 and 82.

87. Where is the compound series-parallel connection used in practice?

Battery cells for gas engine ignition work are connected in this way to give a strong current and a long life. This connection of battery cells is also advantageous in that a dead cell will not weaken the current from the group sufficiently to interfere with the operation of the engine.

PRIMARY BATTERY CELLS

88. How can electricity be generated by chemical action?

By inserting two conducting substances into a solution which dissolves one of them more than the other, a difference of potential will be developed between their ends which are not immersed. If these exposed ends be connected, a current will flow from the one substance to the other, both through the solution and through the exposed connection.

For example, insert the tongue between a copper cent and a silver dime, keeping the coins in contact at one end. A battery cell is thus formed in which copper is one of the elements, silver the other, and the moisture on the tongue the solution. A metallic taste will be noticeable, which indicates that one of the conducting substances is being dissolved or acted upon, and if an electrical measuring instrument of sufficient delicacy be connected in the circuit thus formed, it will be found that a current of electricity is flowing.

To illustrate the case in a more practical way, reference will be made to Fig. 6, in which a plate of zinc *n* and a plate of copper *p* have been immersed in a jar containing water and sulphuric acid. The proportion of water to acid should be about 10 to 1. If these two plates be connected by a wire *a*, as in the illustration, the zinc will dissolve, forming zinc sulphate which will remain in the solution at the surface of the zinc plate, and hydrogen gas will appear in the form of bubbles on the surface of the copper plate. This chemical action will develop a current of electricity which will flow through the wire or external circuit from the copper to the zinc, and through the solution or internal circuit from the zinc to the copper. The current and the chemical action caus-

ing it will continue as long as the acid and zinc last, and there remains a connection between the two plates. If the connecting wire *a* be broken, there will be no chemical action taking place between the copper and the zinc, but there will be a difference of potential of about 1.05 volts across them.

89. In describing the chemical action or reaction of battery cells, what symbols are commonly used?

For water, H_2O; sulphuric acid, H_2SO_4; hydrogen, H_2; zinc, Zn; copper, Cu; for zinc sulphate, $ZnSO_4$; sal-ammoniac,

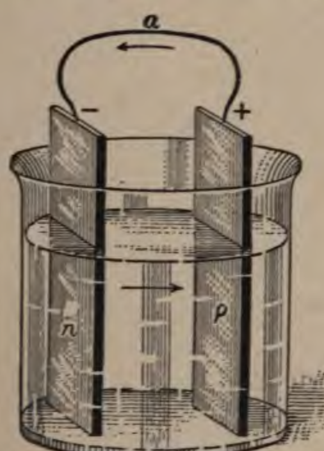


Fig. 6.—Simple Form of Primary Cell.

NH_4Cl; manganese dioxide, MnO_2; zinc chloride, $ZnCl_2$; ammonia, NH_3; manganese oxide, Mn_2O_3; copper sulphate (blue vitriol), $CuSO_4$; potassium bichromate, $K_2Cr_2O_7$; chromium sulphate, $Cr_2(SO_4)_3$; potassium sulphate, K_2SO_4; zinc oxide, ZnO; manganese oxide, MnO; potassium hydrate (caustic potash), KOH; copper oxide, CuO; potassium zincate, K_2ZnO_2; lead oxide, PbO; for lead, Pb; for lead peroxide, PbO_2; for lead sulphate, $PbSO_4$.

90. How, therefore, may the chemical action taking

place in the simple cell illustrated in Fig. 6 be expressed by symbols?

$H_2SO_4 + Zn = ZnSO_4 + H_2$. This, by interpretation, means the sulphuric acid combines with the zinc and forms zinc sulphate and hydrogen.

91. **What relation do the positive and negative elements of a cell bear to the positive and negative poles?**

Those substances which are more readily acted upon or dissolved by the acid solution are called the positive elements, whereas those less acted upon are called negative elements. In the following list the more positive substances are given first, the list ending with those least positive, or, in other words, negative. Inasmuch as the greater the difference in action of the solution upon the two elements of a cell, the greater the electromotive force developed, and other conditions being the same the greater the current, it is evident from the list that zinc and carbon are the two substances best adapted for battery construction, and this statement is borne out in practice, as will be seen later.

+
Zinc
Iron
Tin
Lead
Copper
Silver
Platinum
Carbon
—

The positive pole of a battery cell is that terminal from which the current leaves the cell, and the negative pole is that terminal at which it returns to the cell. It is therefore obvious from Fig. 6 that the copper or negative element constitutes the positive pole, and that the zinc or positive element constitutes the negative pole.

92. **What effect has the size of a cell upon its output?**

The output in watts of a cell is directly proportional to its size, or, in other words, to the amount of material it con-

tains. The electromotive force in volts of a cell depends upon the kinds of material used for the positive and negative plates, and also upon the constituents of the solution employed. In a given type of cell, however, the electromotive force is the same, irrespective of the size of the plates, the quantity of the solution or the shape or size of the jar. The current in amperes that can be obtained from a cell varies inversely as its internal resistance. Since the internal resistance of a cell may be decreased, other conditions remaining the same, by increasing the cross-section of the solution between the elements, it follows that the output of a cell will be increased if more material is employed in its construction; that is, the larger the size of a cell the greater will be its output.

93. Does change of temperature have any effect upon the output of a cell?

Yes, in certain types of cells an increase of temperature causes them to yield a slightly stronger current. This is due to the fact that some solutions decrease in resistance when heated. The electromotive forces of different cells also undergo slight changes in value under variations of temperature. In certain types the electromotive forces increase, and in other types they decrease when subjected to a rise in temperature. In any case, however, the change in the output of a cell, due to change of temperature, is inappreciable.

94. State the difference between a cell and a battery.

The term "cell" is singular, whereas the term "battery" is collective. A battery is, therefore, a number of cells connected together for the purpose of increasing the voltage or current, or of increasing both the voltage and current.

When a voltage greater than is developed by one cell is required, it may be obtained from a battery of two or more cells connected in series as at *A*, Fig 7, that is, by connecting the carbon or + terminal of one cell to the zinc or — terminal of the next cell, and so on. The voltage developed across the free + and — terminals of the external circuit is then equal

to the sum of the electromotive forces of the individual cells. If each of the three cells at *A* gives 1 volt, the voltage of the battery is therefore 3 volts. With a series connection of cells, the battery resistance, however, is also the sum of the resistances of the connected cells; that is, if each of the three cells at *A* has a resistance of 1 ohm, the resistance of the battery is 3 ohms. Consequently, since both the electromotive force and the resistance are increased in the same proportion, the available current output is the same as in a single cell, regardless of the number of cells connected in series. A battery of series connected cells, therefore, gives only a greater electromotive force, so that the current developed can be forced through an external circuit of greater resistance. Cells of different voltages may be connected together in series and their electromotive forces added, without injurious effect.

When a current greater than can be had from one cell is required, it may be obtained from a battery of two or more cells connected in parallel as at *B*, Fig. 7; that is, by connecting the carbon or + terminals of all the cells to one wire of the external circuit, and all the zinc or — terminals to the other. The available current output then equals the sum of the available current outputs of the individual cells, but the voltage across the circuit is only equal to that of one cell. The battery resistance is the resistance of one cell divided by the number of cells in parallel, provided the cells are of equal resistance. Cells which are connected in parallel must have the same electromotive force, else those which have a higher voltage will send a current in the reverse direction through the cells of lower voltage when the external circuit is open. This will soon reduce the strength of the cells having the higher electromotive force, and should serve as a warning that it is useless to connect a new cell in parallel with others that are old and partly exhausted. A battery of parallel connected cells should be composed of cells all of the same make and in the same electrical condition.

When a voltage and a current greater than developed by one cell are required, they may be obtained from a battery of

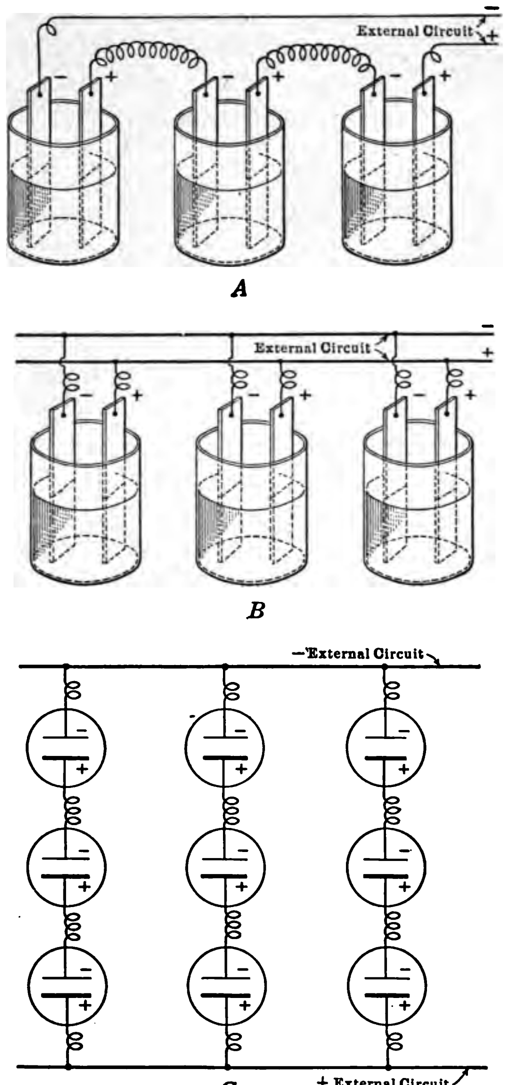


Fig. 7.—Different Forms of Battery Circuits.
(A) Series. (B) Parallel. (C) Series-Parallel.

four or more cells connected in series-parallel as at *C*, Fig. 7; that is, by connecting in parallel across the external circuit several rows of cells, each row having the same number of cells in series. Unless each row of cells connected in this way develops the same voltage, the action will be the same as in the case of a parallel connection where one cell has a higher voltage than the others.

95. How many classes of primary cells are there?

Three. Single fluid cells, or those in which one solution is employed; double fluid cells, or those in which two solutions are employed; and dry cells, or those in which the solution is replaced by a plastic mass.

96. In which of the three classes of primary cells referred to in Answer 95 does the simple cell illustrated in Fig. 6 belong?

It belongs to the class of single fluid cells, inasmuch as there is but one solution (dilute sulphuric acid) employed.

QUALIFICATIONS FOR SERVICE

97. Is the cell illustrated in Fig. 6 suitable for practical purposes?

The positive element in this cell being an ordinary plate of zinc contains many impurities such as lead, iron, etc., which according to the list given in Answer 91 are negative with respect to the zinc, and therefore give rise to small electric currents between them and the zinc. These currents, although of diminutive strength, continue to flow irrespective of the action of the cell itself, and thus steadily consume the zinc both when the cell is on open circuit and when it is on closed circuit. This is called the local action of a cell, and it must be eliminated if the cell is to be adapted to practical purposes.

Another disadvantage of the cell illustrated in Fig. 6 is that no means is provided therein to oxidize or otherwise get rid of the bubbles of hydrogen gas which accumulate upon the

surface of the negative element as already explained. These bubbles form a non-conducting film over the surface of the copper plate presented to the solution, when the cell is in action, and thus greatly increase the internal resistance of the cell, which in turn reduces the current. In addition to this, the hydrogen bubbles also weaken the current by generating in the cell an opposing or counter electromotive force which tends to start a current in a direction opposite to that of the normal current flowing within the cell from the zinc to the copper. The result of the hydrogen gas effect, or polarization, as it is called, is to diminish the current very rapidly after the circuit through the cell has been closed. It is therefore important whenever a constant current is required, as is invariably the case in practical work, that means be taken to prevent polarization as far as possible.

98. How may the local action of a battery cell be remedied?

By amalgamating the positive or zinc element with mercury. This may be done either before or after the zinc has been cast into plates or rods for use, although it is more usually done before the casting process. In this case about 4 per cent. of mercury is added to the molten zinc just before turning it into the molds. Battery zincs sold as such are amalgamated in this way. If it be desired to amalgamate zinc after being cast in the desired form, it is first necessary to clean its surface by dipping it in acid. This will insure a good surface for the mercury, which should then be poured over it and rubbed in with a piece of cloth tied to a stick. The mercury combines with the zinc at the surface of the plate or rod, and forms a pasty amalgam. The lead, iron and other impurities then float to the surface of the mercury when the zinc is in use, and fall to the bottom of the containing vessel. During the action of the cell the zinc in the amalgam unites with the acid, and the film of mercury combining with fresh portions of the zinc always causes it to present a clean surface to the solution.

99. In what ways may the polarization of a battery cell be remedied?

Polarization may be remedied either by mechanical means, by chemical means or by electro-chemical means. One of the mechanical methods for getting rid of the hydrogen bubbles on the negative element consists in brushing them off with some non-conductor, or dispersing them by stirring or otherwise agitating the solution so as to keep it in motion. Hydrogen gas, owing to its low specific gravity, has a tendency to rise through the solution, but this tendency is not sufficiently strong ordinarily to cause the bubbles to detach themselves from the negative element. To mechanically aid them in this respect, the surface of the negative element may be roughened or made to present numerous points to the solution so that the bubbles secure less purchase on the plate and are enabled thereby to detach themselves.

The chemical method of preventing polarization consists in adding to the solution some oxidizing substance such as manganese dioxide, oxide of copper, peroxide of lead, sulphur, chlorine, bromine, red lead, nitrate of potash, bichromate of potash, nitric acid, chromic acid, bichromate of soda, or ferric chloride, which will combine chemically with the hydrogen gas and form a substance that will dissolve in the solution. In general, the best oxidizing substances or depolarizers are liquids, as they act more quickly than the others, but as a rule they will attack copper and so cannot be used in a cell where copper forms the negative element. Carbon, however, is not thus affected, and as it is also more electro-negative than copper, according to the list given in Answer 91, carbon is generally employed in place of copper for the negative element in cells where polarization is prevented by chemical means. When the oxidizing substance or depolarizer is in powdered form, it is generally packed around the carbon in a very porous earthenware cup. The cup keeps the depolarizer in place, but is sufficiently porous to permit the battery solution to pass through it.

The electro-chemical method of eliminating polarization is

in the use of double fluid cells. By thus employing two solutions, some metal, such as copper, can be liberated in place of the hydrogen, and polarization be thus entirely prevented.

100. What other defects are of common occurrence in the operation of primary battery cells?

Internal short circuits caused by crystals or foreign matter lodging between the elements within the jar; abnormally high internal resistance resulting from the use of defective porous cups, poor connections at the terminals, or by the accumulation of crystals upon the positive element; low electromotive force resulting from the use of an exhausted solution.

101. How may the defects given in Answer 100 be remedied?

Internal short circuits may be remedied by emptying out the solution, thoroughly cleaning and soaking the elements and the jar, and using a fresh solution. In mixing the fresh solution, care must be taken that the water used contains no impurities. If there be a tendency for the salt crystals from the solution to creep over the edge of the jar and thus short-circuit the cell, it is advisable to dip the edge of the jar in melted paraffin to a depth of about an inch. This will effectually prevent the creeping of the salt.

Porous cups, after long usage, are liable to have the pores in their sides and bottom clogged up, and thus considerably increase the internal resistance of a battery cell. When thus affected they generally take on a brownish color, whereas when in perfect condition they are nearly white. Their pores may be cleared by placing the porous cup in boiling-hot water and allowing it to remain there for ten or fifteen minutes.

Poor connections at the terminals are generally caused by dirt or corrosion; this can best be removed by the use of fine sandpaper or by scraping with a knife the terminals and the conductors connecting with them. It may be, however, that the conductors are not tightly screwed to the terminals; in

which case, of course, the remedy consists in tightening them.

If crystals accumulate on the positive element, it should be removed from the jar and scraped clean. The solution should also be diluted, as the defect here mentioned is an indication that the solution contains too much salt.

An exhausted solution can generally be detected by a change in its appearance, as will later be described; this, therefore, serves as a warning that the solution must be either strengthened or thrown away, according to the nature of its constituents.

COMMERCIAL TYPES

102. What are the commercial types of primary cells?

The Leclanché, carbon cylinder, bichromate, Edison, gravity, and dry cell.

103. Illustrate and describe the Leclanché cell.

A common form of Leclanché cell is shown in Fig. 8. It consists of a glass jar *d* containing a solution of ammonium chloride, commonly called sal-ammoniac. In this solution is placed a porous cup *a*, which contains a carbon plate *s* packed with small pieces of carbon and granulated peroxide of manganese. The solution passes through the porous cup and moistens its contents, of which the manganese dioxide is the depolarizer and the crushed carbon is used to reduce the internal resistance so as to increase the current output. The top of the cup is sealed with bitumen, but two small openings at *e* are left in it to act as gas vents, and through which a few tablespoons of the solution may be poured when the cell is first set up, to hasten its action. The carbon *s* is the negative element of the cell, and the zinc rod *n* immersed in the sal-ammoniac solution forms the positive element. About 6 ounces of sal-ammoniac constitutes a charge; after this has been placed in the jar it should be filled with pure, soft water to the height shown in the illustration.

During the action of the cell the zinc is dissolved, forming chloride of zinc, and hydrogen gas and ammonia gas are given

off. The hydrogen gas being released at the surface of the carbon plate is at once attacked by the manganese dioxide within the porous cup and is converted into water and oxide of manganese. The ammonia gas dissolves in the water until a saturated solution is formed, after which it evaporates. The chemical reaction is

$$Zn + 2NH_4Cl + 2MnO_2 = ZnCl_2 + 2NH_3 + H_2O + Mn_2O_3.$$

For each ounce of zinc dissolved, 2 ounces of manganese dioxide and 2 ounces of sal-ammoniac must be consumed.

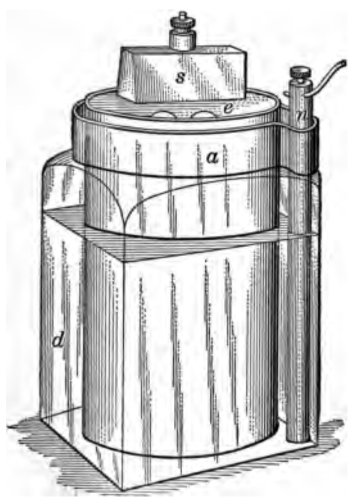


Fig. 8.—Leclanché Cell.

From the quantities of these materials contained in the ordinary size of Leclanché cell, there is sufficient manganese dioxide in the porous cup to last the life of four zinc rods, but only enough sal-ammoniac in the solution to last the life of one and one-half zinc rods. As it is customary to work the zinc rods to the very last stages, about 1/8 inch in diameter, the contents of the porous cup should last the life of about six zinc rods, and the sal-ammoniac should last the life of two zinc rods. Each ounce of zinc in this cell produces about 23

ampere-hours, and as approximately 1 3/4 ounces are utilized from each zinc rod, one of these rods may be counted on to produce 40 ampere-hours.

The Leclanché cell is of the single fluid type, and is used only in open circuit work such as for door bells, telephone bells and other signals of a similar nature. It will polarize if worked hard or short-circuited, but will recuperate very quickly. It will not run down when not in use, and will frequently do duty for over a year with only the addition of a small quantity of water to compensate for evaporation. The evaporation is less rapid if the cell be in a cool place.

If the solution becomes too strong, crystals composed of the double salts of zinc and ammonium chloride will be deposited on the zinc rod, whereas if it becomes too weak, chloride of zinc will form on the zinc rod. In either case, the internal resistance of the cell will be increased and its efficiency lowered. Moreover, if more sal-ammoniac is used than will dissolve, the bottom portion of the solution will be denser than the top portion, and, besides, will contain some zinc chloride. This will set up local action due to the two densities of the liquid and will be indicated by the upper part of the zinc rod wasting away faster than the lower portion. Where the zinc corrodes or wastes away at the surface of the liquid only, it is probably due to oxidation and not to faulty solution. An old solution smells strongly of ammonia, and the stronger the odor the older the solution; this, therefore, serves as a guide as to when the solution needs renewing. When the solution takes on a milky appearance, it is also an indication that it is exhausted and must be renewed. The electromotive force of this cell is 1.48 volts, and its internal resistance is about 4 ohms.

104. Illustrate and describe the carbon cylinder cell.

Fig. 9 shows this type of primary cell. The carbon is in the form of a cylinder as shown at *c*, and is molded in one piece with the cover so as to form a perfect seal for the cell and prevent evaporation of the solution or the climbing of

salts. The carbon is a solid mass, but the surface of the cylindrical part is purposely roughened to facilitate the escape of the bubbles of hydrogen gas which collect on it during the action of the cell. Owing to the slight hold these bubbles can secure on the carbon on account of its roughened surface and the fact that the hydrogen gas is so much lighter than the solution, there is a strong tendency for the bubbles to work themselves loose from the carbon and escape upward

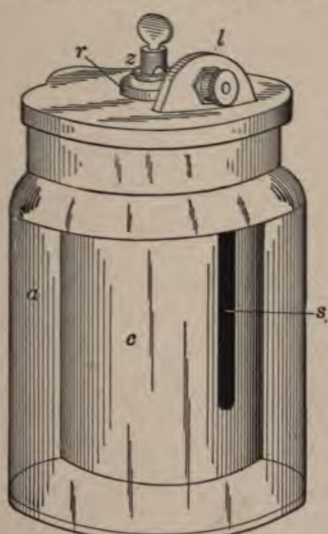


Fig. 9.—Carbon Cylinder Cell.

through the solution. So effective is this action that no other means are provided for preventing polarization.

The solution is the same as in the Leclanché cell described in Answer 103; that is, sal-ammoniac and water, about 6 ounces of the former in the glass jar *a* filled two-thirds full of water. The solution has free access to both outer and inner surfaces of the carbon cylinder, and to the zinc rod *z* inside, through the lower part of the cylinder, which is entirely open and suspended above the bottom of the glass jar, and through the slot *s* cut in the side. The zinc is suspended by a porce-

lain insulator *r* through the center of the carbon cylinder, the insulator extending down only through the cover. The carbon lug *l* molded into the cover holds a binding post for wire connection with the carbon.

During the action of the cell, the zinc is dissolved, forming chloride of zinc, and ammonia gas and hydrogen gas are given off. The ammonia gas dissolves in the water until a saturated solution is formed, after which it evaporates. The hydrogen gas is released at the roughened surface of the carbon and, as previously explained, the bubbles quickly detach themselves and pass upward through the solution to be evaporated when they reach the surface. The chemical reaction is

$$Zn + 2NH_4Cl = ZnCl_2 + 2NH_3 + 2H.$$

The carbon cylinder cell, like the Leclanché cell, is intended only for intermittent work such as for door bells, etc. It has the same electromotive force of 1.48 volts, but a somewhat lower internal resistance than 4 ohms, owing to the absence of a porous cup and the circular arrangement of the carbon around the zinc. The cell recovers quickly after hard work, and owing to its simple construction and no need of a depolarizer it has largely replaced the Leclanché as a liquid cell for intermittent work.

105. Illustrate and describe the bichromate cell.

The bichromate cell is shown in Fig. 10. It consists of two plates of carbon *n* and *s*, the respective terminals of which are shown at *c* and *e;* in practice, these terminals are connected together and used as the positive pole of the cell. The terminal *m* of the zinc plate *a* forms the negative pole of the cell. The elements are immersed in a solution of bichromate of potash formed by dissolving 4 ounces of bichromate of potash in 1 quart of warm water, and slowly adding to this when cool 2 fluid ounces of sulphuric acid, which should be well stirred into the dissolved bichromate of potash, with a glass rod.

During the action of the cell the following change takes place:

$$3Zn + 7H_2SO_4 + K_2Cr_2O_7 = 3ZnSO_4 + Cr_2(SO_4)_3 + K_2SO_4 + 7H_2O.$$

The solution acts upon the zinc plate by ordinary chemical action even when producing no current. The zinc plate is therefore attached to a rod *v*, which not only serves as a conductor, but enables the zinc to be drawn up out of the solution when the cell is not in use.

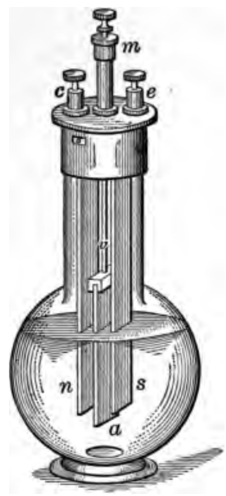


Fig. 10.—Bichromate Cell.

The bichromate cell is of the single fluid type. It cannot be used steadily for more than a few hours, since after that time it becomes polarized, but it is well adapted for experimental work and for operating small electric motors. The solution when first mixed is of a cherry-red color, but after a few hours of service it becomes dark brown, indicating exhaustion; it is then useless and has to be thrown away and replaced by a fresh quantity. The electromotive force of this cell is from 1.92 to 2 volts, and in consequence of a low internal resistance it yields a large current.

106. Illustrate and describe the Edison cell.

The Edison cell, formerly known as the Edison-Lalande cell, is shown in Fig. 11. It consists of two amalgamated zinc

Cu

plates *a* and *c*, and one copper oxide plate *e* suspended from the porcelain cover *m* into a porcelain jar containing a solution of caustic potash. The zinc plates *a* and *c* together form the positive element and are connected to the negative terminal *n* by means of the conducting strips *s* and *v*. The copper oxide plate *e* is covered with a film of metallic copper so as to decrease the internal resistance of the cell when first

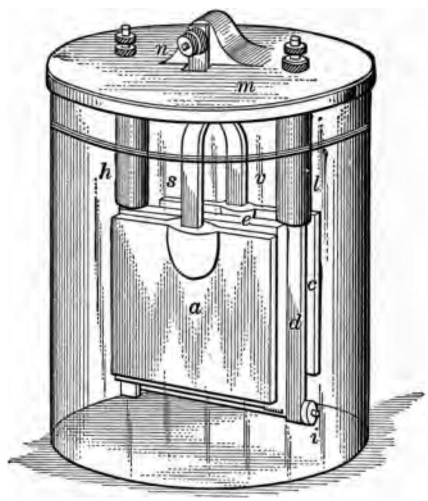


Fig. 11.—Edison Primary Cell.

started. This plate is slid from below into two channeled copper frame-sides, one of which is shown at *d*, and is secured therein by a copper bolt terminating in a nut *i*. Two hollow, hard-rubber insulators *h* and *l* surround the stems holding the copper oxide plate in position, for the purpose of preventing any internal short-circuits between these stems and the strips *s* and *v*, at the surface of the solution.

The solution, which should fill the jar to within an inch of the top, is made by dissolving 2 pounds of granulated caustic potash in 8 pounds of water. A layer of heavy paraffin oil is poured on top of the solution to prevent any creeping of the salts and evaporation of the solution. When the oil is

not used, the life of the cell is reduced to about one-third what it otherwise would be.

During the action of the cell, the zinc dissolves, forming potassium zincate (K_2ZnO_2). Hydrogen gas is given off and is carried by the current to the negative plate, where it unites with the copper oxide and forms water and metallic copper. The reaction may therefore be written:

$$Zn + 2KOH + CuO = K_2ZnO_2 + H_2O + Cu.$$

The Edison cell is of the single fluid type. It requires no attention or inspection until all the energy of its elements is exhausted. It is entirely free from noxious fumes or chemical deposits, the liquid does not "creep," there is no polarization and practically no local action, and the cell will not freeze at a temperature considerably below zero.

It has an electromotive force of but 0.95 volt at the start, and this decreases to 0.7 volt on closed circuit. The internal resistance of this cell, however, is exceptionally low, being only 0.043 ohm. The current that may be obtained is therefore high, and in the case just noted would be $0.7 \div 0.043 = 16.3$ amperes on short circuit. The Edison cell is consequently well adapted to cases requiring strong battery current almost continuously, as, for example, in gas engines, railroad crossing signals, fan motors, dental motors, phonographs, turntable motors, large annunciators, and in electroplating and slot machines.

To set up this cell, fill the jar with pure, soft water to the brown line that is on the inside of the jar. Add the granulated potash from the can furnished with the battery, quite gradually to avoid producing too much heat, and stir the solution continuously until the potash is entirely dissolved. Care should be exercised to avoid splashing or spilling of the liquid, as the caustic potash solution will burn either the skin or the clothes. Allow the solution to cool and add enough water to bring the solution up again to the brown line. Put the elements in place and note whether the copper oxide plate *e* is one inch below the surface of the solution. It is very

essential that the liquid be one inch above the top of the oxide plate. If it is, then raise the cover only just enough to permit of the paraffin oil, furnished with the battery, being poured into the cell until it just covers the blue line. If the cover is raised too high, the paraffin will get on the battery plates. Vegetable or animal oils should never be used instead of paraffin, as they will be attacked by the solution.

When the cell becomes exhausted, proceed as follows: Lift the cover off carefully to avoid contact with the solution, and thoroughly wash all the parts before handling. Remove both the zinc and the oxide plates from the porcelain cover and throw the plates away. Carefully pour out the solution and wash the jar. Wash the copper frame *d* and clean out the inside of the groove, as the frame is to be used again. Replace the discarded plates with new ones and set up the cell exactly as in the case of a new cell.

107. Illustrate and describe the gravity cell.

The gravity cell is illustrated in Fig. 12. This cell belongs in the double fluid class, and the name of the cell results from the fact that the two solutions used are separated by gravity. The negative element is copper in the form of copper plates *b* riveted together as shown, connection therewith being made by means of a gutta-percha insulated wire *c* fastened to them at *a*. The positive element is zinc, as shown at *v;* this is suspended from the metallic hangers resting across the top of the jar *o*. In this case the hanger forms the negative terminal of the battery, and to it the wire *e* is fastened.

The solutions are formed by first placing in the bottom of the jar about 3 pounds of copper sulphate crystals, or blue vitriol, as it is often called. Sufficient water is then poured in the jar to cover the zinc *v*, and a tablespoonful of sulphuric acid is added. Within a short time a bright blue, saturated solution of copper sulphate forms about the copper plates, and after the cell is in use a water-colored solution of zinc sulphate is formed about the zinc.

The zinc sulphate solution, being lighter than the copper sulphate solution, floats upon the latter, maintaining at all times a distinct dividing line between them, as shown at *z*. This line is commonly known as the blue line, and its position serves as a guide in the proper maintenance of the cell. The blue line should be kept midway between the copper and

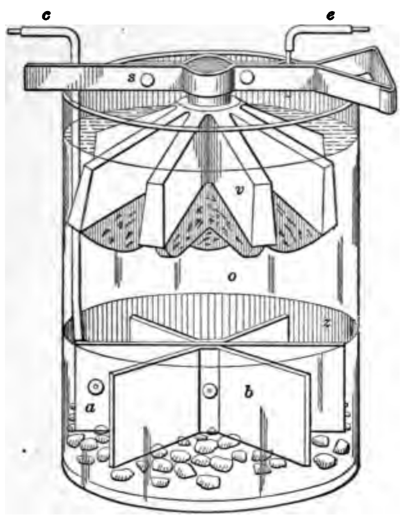


Fig. 12.—Gravity Cell.

the zinc; if it becomes low in the jar a portion of the zinc sulphate should be dipped out and replaced with clear water; whereas if it becomes too high, a portion of the copper sulphate must be siphoned out and water added. A brownish color in any part of the liquid indicates exhaustion of the solution.

During the action of the cell the copper sulphate unites with the zinc, forming zinc sulphate and metallic copper. The reaction may therefore be written:

$$CuSO_4 + Zn = ZnSO_4 + Cu.$$

The gravity cell has an electromotive force of 1.1 volts and an internal resistance of from 2 to 3 ohms. It can therefore be counted upon to give currents of only small strength, but

it does not polarize, and works best on closed circuit. It is used mostly for telegraph and telephone purposes.

108. Illustrate and describe the dry cell.

A dry cell was previously shown in Fig. 1, but reference will here be made to Fig. 13, which shows a cell broken open at the bottom to afford an idea of its construction.

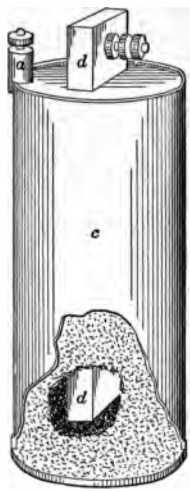


Fig. 13.—Dry Cell.

This cell consists of a zinc tube or cylinder *c* 2.5 inches in diameter and 6 inches deep, which constitutes the containing vessel and also serves as the positive element of the cell. The binding post *a* soldered to the zinc *c* forms the negative terminal of the cell. Closely fitting inside the zinc cylinder is a porous paper cylinder which holds the negative element or carbon plate *d* surrounded by a mixture of manganese dioxide, etc. Connection with the negative element is made at the positive terminal mounted on the carbon.

The zinc cylinder is rolled from zinc 0.02 inch thick; the paper cylinder may consist of three layers of thin blotting paper or a single layer of heavy pulp-board; the mixture surrounding the carbon plate consists of pyrolusite (85 per

cent. manganese dioxide), 100 parts by weight; ground coke, 80 parts; artificial graphite, 20 parts; sal-ammoniac, 20 parts, and zinc chloride, 7 parts. The top of the cell thus formed is sealed with bitumen, shown black in the illustration, to hold in the contents and prevent evaporation as much as possible.

The manganese dioxide acts as the depolarizer; the ground carbon which is next to the paper cylinder collects the current at the periphery of the mixture and conducts it by means of the other carbon particles to the center carbon plate; the graphite is employed to reduce the internal resistance; the sal-ammoniac is the electrolyte or exciting substance, while the zinc chloride is used only to improve the life of the cell by reducing local action.

During the action of the cell the chemicals are decomposed, the reaction being as follows:

$$Zn + MnO_2 = ZnO + MnO.$$

This cell is comparatively free from the effects of polarization, but its useful life is generally much shorter than that of a similar form of liquid cell, such, for example, as the Leclanché cell previously illustrated and described.

The idea that a dry cell can be recharged after it has outlived its usefulness, by passing a current through it, is erroneous, as the current has no such effect upon the chemicals composing the cell. Sometimes an exhausted cell can be made to work again by drilling a small hole through the sealing at the top and pouring in a little water or sal-ammoniac solution.

The electromotive force of the dry cell is 1.4 volts, its internal resistance is about 0.3 ohm and during its life it gives a practically constant electromotive force. The dry cell is intended for open circuit work only, and is commonly used for electric bells, telephones, etc.; it is very convenient for portable use and in the hands of unskilled persons, since its contents cannot be spilled, as in the case of liquid cells, and there is no creeping of salts or any of the other internal troubles associated with the use of other types of primary cells.

STORAGE BATTERY CELLS

109. What difference is there between a storage battery cell and a primary battery cell?

In a primary battery cell electricity is generated, as has already been shown, by the solution acting upon one of the elements to a greater extent than upon the other. In a storage battery cell, the solution is decomposed by the passage of a current of electricity through it, and after the source of this current has been removed the cell may be made to return this current or a portion of it whenever desired. In a primary cell, electricity is generated, but one of the elements and the solution are used up during the process and have to be renewed from time to time. In the storage cell, electricity is not generated, but is simply stored as it were, to be used again at some future period; the elements and solution are not used up as in the case of a primary cell, but may be used over and over again.

110. Are storage battery cells known by any other name?

Yes, they are sometimes called secondary cells to distinguish them from primary cells.

The term "storage battery," however, is generally used in preference to "secondary cells" for the reason that the former is more significant of the action taking place. In reality, however, a storage battery does not store electricity, but simply energy, by converting the active energy of a current of electricity into chemical energy and at some future time, as determined by the operator, converting the chemical energy back into the active energy of an electric current.

There are certain losses occurring in the transformation process, among which is that due to the internal resistance of

the battery. These losses reduce the output of a storage battery cell from its input to the extent of about 20 per cent., making the maximum efficiency of this type of battery cell around 80 per cent.

111. Does the construction of a secondary or storage battery cell differ from that of a primary cell?

There are many types of primary cells, as, for example, the gravity cell, which when exhausted may be regenerated by sending a current from some external source through it in a direction opposite to that of the current which it generates. By so doing the zinc sulphate and the metallic copper are changed respectively into metallic zinc and copper sulphate. This reaction is the reverse of that previously given for the gravity cell, and theoretically would enable this cell to fulfill the functions of a storage battery cell, but in practice the sulphate solution and the copper salt together reach the negative plate and are deposited there, creating local action. It is thus seen that, whereas a primary cell may to a certain extent meet the conditions of a storage cell, it cannot be made to answer as such for practical purposes; it is therefore customary to consider as storage batteries only those cells which have been specially constructed to serve in that capacity.

112. Describe the general principles upon which the construction and operation of a storage battery cell are based.

A storage battery cell consists essentially of two sets of metal or metallic oxide plates immersed in a solution which will not act upon them until a current of electricity is passed through the cell from one set of plates to the other. In the ordinary type of cell the plates are of lead and the solution is sulphuric acid diluted with water to a specific gravity of about 1.200. The passage of the charging current through the solution decomposes it, sending one of its constituents to one set of plates and the other constituent to the other set of plates. When the charging current is discontinued, there are therefore two chemical elements in the plates which have a

tendency to unite, and when allowed to do so the energy developed asserts itself in the form of an electric current. This current flows in a direction opposite to that of the current used in charging the cell, and if permitted will continue to flow in this manner until the plates have attained their former state.

113. How are the principles given in Answer 112 applied in practice?

In modern types of lead storage battery cells the surface of the positive set of plates is coated with lead oxide or litharge

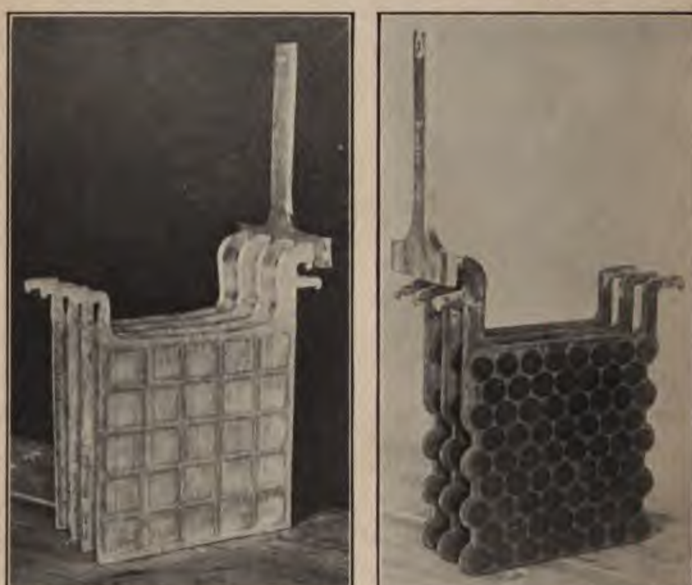


Fig. 14.—Storage Battery Plates for a Single Cell. Negative Group of Four at the Left; Positive Group of Three at the Right.

(PbO), lead peroxide (PbO_2), minium or red lead (Pb_2O_3), lead sulphate ($PbSO_4$), or a mixture containing these substances, so that the charging current will convert it into lead peroxide. The negative set of plates is of pure lead, the surface of which is spongy or porous in its formation. A set of

four negative plates is shown in Fig. 14, at the left. The method of applying the substances mentioned to the positive plates consists either in forming a paste of whichever substance is selected, by the addition of water or sulphuric acid, or else using the substance in the form of a powder and forcing it into the lead plates by means of hydraulic pressure. For enabling the plates to receive and retain the substance used, they are sometimes roughened at the surface, but more usually are cast into grids having round, square or rectangular openings into which the material is pressed. When the plates are made in this way, they have an appearance, when finished, similar to the set shown at the right of Fig. 14. The material pressed into the grids and the spongy lead are practically the only active portions of the plates, the plates themselves serving principally as a support for these substances.

The positive plates in a storage cell, of which there is always one less than the number of negative plates, for the reason that will be given later, are all connected together, and the negative plates are also connected together; their relative positions in the cell, however, are such that the positive and negative plates alternate with each other, but they are prevented from coming together by sheets of insulating material.

The storage battery jar holding the plates and solution is made of non-conducting, acid-proof material. For portable use, lightness of weight is an important requisite, whereas for station work it does not matter how heavy the jars are. In the former case the jars are made of glass, of hard wood lined with lead, or of hard rubber, hard rubber being especially adapted to the purpose; in the latter case the jars are made of heavy glass, or of heavy planks, jointed, and lined with sheet lead.

114. Which is the positive and which is the negative element of a storage cell?

In a primary cell it will be remembered that the element toward which the current in the external circuit flows is called

positive, and that from which the current flows is called negative. In like manner the element or set of plates in a storage cell toward which the current flows during discharge is called positive, and the other element or set of plates is called negative. Since in the charging process current is forced through the cell in the opposite direction to that of the discharging current, it might be supposed the terms as just applied would then be incorrect, but inasmuch as the set of plates upon which a coating of peroxide of lead is formed always remains at a higher potential than the other set composed of spongy lead even when current is forced through the cell, as just explained, the notation given is warranted. The peroxide of lead plates therefore form the positive element, and the spongy lead plates form the negative element of a storage cell.

Inasmuch as the plates of the positive element are the ones acted upon during the discharge of the cell, in the same respect as the positive zinc element in a primary cell is acted upon, it is customary to use for the negative element in each cell one more negative plate than there are positive plates.

115. What chemical reaction takes place during the charging process?

In practice, both the positive and negative plates contain lead sulphate formed on them by the preceding discharge. The action of the charging current in its passage through the cell from the negative plates to the positive plates, breaks up the sulphate of lead into sulphuric acid and also transfers the oxygen from the negative to the positive plates. When the charging process is completed, the positive plates contain no oxide lower than the peroxide, and the negative plates contain no oxide whatever. Owing to the formation of sulphuric acid, the specific gravity of the solution has been increased during the charging process.

When red lead salt constitutes the active material, the chemical reaction that takes place at the positive plates during the charging process is

$$S_2Pb_3O_{10} + O_2 + 2H_2O = 3PbO_2 + 2H_2SO_4.$$

That is to say, the red lead salt ($S_2Pb_3O_{10}$), the oxygen (O_2) and the water (H_2O) are converted by the charging current into lead peroxide (PbO_2) and sulphuric acid (H_2SO_4).

The chemical reaction that takes place at the negative plates during the charging process is

$$S_2Pb_3O_{10} + 4H_2 = 3Pb + 2H_2SO_4 + 2H_2O.$$

This by interpretation means that the red lead salt ($S_2Pb_3O_{10}$) and the hydrogen (H_2) are converted by the charging current into metallic lead (Pb), sulphuric acid (H_2SO_4) and water (H_2O).

116. What chemical reaction takes place during the discharging process?

In discharging, the sulphur contained in the sulphuric acid of the solution unites with the active material on both positive and negative plates and forms lead sulphate, at the same time lowering the specific gravity of the solution. When the cell is entirely discharged, the difference of potential between the positive and negative plates becomes zero, and a state of equilibrium is established. In practice, however, the discharge should never be allowed to advance this far, as it is injurious to the plates; thus, when the difference of potential per battery cell becomes as low as 1.75 volts, the cell should not be discharged further.

When red lead salt constitutes the active material, the chemical reaction that takes place at the positive plates during the discharging process is

$$3PbO_2 + 2H_2SO_4 + 2H_2 = S_2Pb_3O_{10} + 4H_2O.$$

This change is practically the reverse of that which occurs at the positive plates during the charging process.

At the negative plates during the discharge of this storage cell, the reaction is

$$3Pb + 2H_2SO_4 + 2O_2 = S_2Pb_3O_{10} + 2H_2O.$$

This, also, is practically the reverse of the reaction previously given for the negative plates during the charging process.

COMMERCIAL TYPES

117. **Illustrate and describe a storage cell in which the lead type of plates shown in Fig. 14 is used.**

The storage cell shown in Fig. 15, and manufactured by The Electric Storage Battery Company, contains this type of plates. In the form here shown it consists of four negative plates, *a*, etc., each of which terminates in a leaden lug *c*. These four lugs are soldered to a lead plate strap *m*, the upper

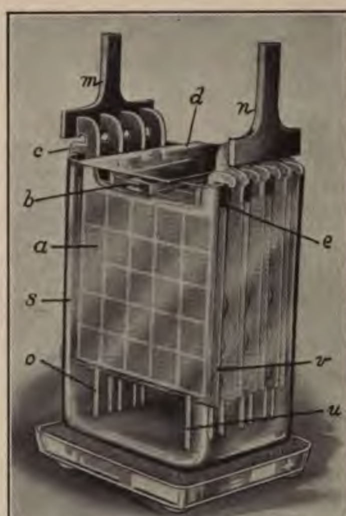


Fig. 15.—Storge Cell made by The Electric Storage Battery Company.

part of which forms the negative terminal of the cell. Alternating with the four negative plates are the three positive plates *e*, etc., inserted between them. The positive plates also terminate in lugs which are soldered to a lead strap *n*, the upper part of which forms the positive terminal of the cell. The negative plates are of pure lead and have a gray color, whereas the positive plates are brown and have their active material in the form of round buttons which, when the cell is charged, consist of peroxide of lead.

A thin wood sheet *v*, with two slotted dowels *o* and *u*, is placed between each positive and negative plate to prevent internal short circuits. These wooden sheets are called separators. The elements thus assembled are placed in a glass jar *s* containing a solution of sulphuric acid and pure water, in such proportions that the mixture shows a specific gravity of 1.210 when the cell is fully charged. The solution should fill the jar to a point 3/4 inch above the tops of the plates.

A glass weight *b* prevents the wood separators from floating in the solution, and a glass sheet *d* is placed on top of the jar to keep out impurities and reduce evaporation. The electromotive force of this cell is slightly above 2 volts on open circuit, and during discharge it varies from that point at the beginning to 1.75 volts at the end of 8 hours.

118. Illustrate and describe some other make of lead plate storage cell.

The Gould storage cell shown in Fig. 16 is another example of the lead type. In the construction of this cell the positive plates *p*, etc., through their lugs *v*, etc., are connected with the cross bar *r* to the positive strap *a*, and the negative plates *n*, etc., are connected through the cross bar *s* to the negative strap *c*.

Between each positive and negative plate is a perforated hard rubber sheet *b* and a wooden separator *i*. The rubber sheet is placed next to the positive plate and the wooden separator next to the negative plate. One side of the separator is grooved and the other side is flat; the former is placed against the rubber sheet, and the latter against the negative plate.

The plates, sheets and separators rest upon two bridges, one of which is shown at *l*, and are held down by a bar *m* on each side. The form of cell shown is used in electric vehicles and has a hard rubber jar *h*, and a hard rubber cover *d* provided with a vent *e* for the escape of gases formed during the charge.

The jar has been broken away, as shown, to render the

plates, sheets and separators visible; these latter parts of the cell have also been broken away in the illustration for a similar purpose. The electromotive force of this cell on open circuit with solution above the plates is 2.1 volts.

Fig. 16.—Storage Cell made by the Gould Storage Battery Company.

119. Is there any other commercial storage cell besides the lead type previously described?

Yes, there is the nickel-iron type made by the Edison Storage Battery Company.

120. Illustrate and describe the Edison storage cell of the nickel-iron type.

This cell is shown in Fig. 17, the steel can or jar and the plates being broken away to show the construction. The flat plate *n* to the left is the negative element. This is made up of a nickel-plated steel grid, into the openings of which are placed and hydraulically pressed perforated and corrugated

steel pockets, *c*. These pockets are previously filled and packed with iron oxide, to which a small percentage of metallic mercury has been added to increase the electrical conductivity.

The plate *p* to the right is the positive element. It consists of a nickeled steel grid, onto which are secured perforated steel tubes *t* reinforced by equally spaced steel seamless rings.

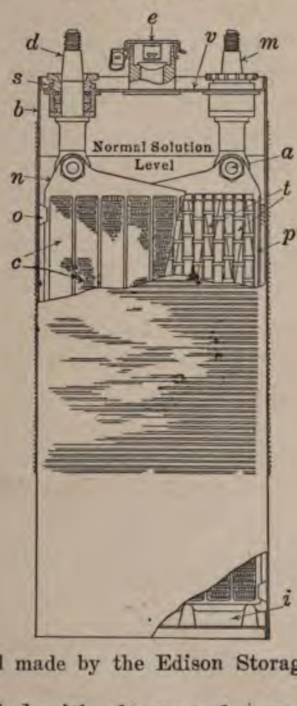


Fig. 17.—Storage Cell made by the Edison Storage Battery Company.

These tubes are filled with alternate layers of nickel hydrate and very thin flake nickel. The nickel hydrate comprises the active material, while the metallic nickel acts as a conductor between the active material and the containing tube. There are 350 layers of each kind in the tube.

The proper number of positive plates, depending upon the desired capacity of the cell, are mounted on the horizontal rod *a* and spaced by nickeled steel washers, the whole being clamped to the pole *m* by the end nuts on the horizontal rod.

The negative plates are similarly mounted and clamped to the pole *d*, there being always one more negative than positive plate.

The two groups are then assembled, the adjacent positive and negative plates being mechanically separated by vertical, hard rubber rods. The edges of the plates fit into grooves of a hard rubber insulator *o* at the sides. The entire mass is then placed into the corrugated steel can or jar *b*, resting on the hard rubber supports shown at *i* in the broken away lower corner of the cell.

The bottom of the steel jar is welded in, and after the elements are placed inside, the cover *v* is also welded on, thus producing, with the stuffing boxes *s*, around the poles, a compact, strong, hermetically sealed vessel. The electrolyte is a solution of potassium hydrate and lithium hydrate. The filling cap, shown at *e* on the top of the jar, when opened, admits of the addition of distilled water to the cell from time to time or for removal of the solution at the end of ten or twelve months of use, depending upon the work to which the battery has been subjected. This filling cap also acts as a check valve to permit the gas given off by the cell to get out, but preventing external air or foreign substances from getting into the cell.

The voltage per cell at the normal rate of discharge is 1.2, and the efficiency ranges from 60 to 65 per cent.

121. What chemical reactions take place during the charging and discharging of the nickel-iron storage cell?

Starting with oxide of iron in the negative, green nickel hydrate in the positive, and potassium hydrate in solution, the first charging of a cell reduces the iron oxide to metallic iron and converts the nickel hydrate into a very high oxide black in color. On discharge, the metallic iron goes back to iron oxide and the high nickel oxide goes to a lower oxide, but not to its original form of green hydrate. On every cycle thereafter, the negative charges to metallic iron and discharges to iron oxide, while the positive charges to a high nickel oxide.

Current passing in direction of charge or discharge, decomposes the potassium hydrate of the solution, but an amount equal to that decomposed is always reformed at one set of plates by a secondary chemical reaction, so there is none of it lost and the density of the solution remains constant.

The eventual result of charging, therefore, is the transference of oxygen from the iron to the nickel plates, and that of discharging is a transference back again.

PRACTICAL APPLICATIONS

122. For what purposes are storage cells employed?

Storage cells are used to a great extent in place of primary cells for operating telephone, telegraph, fire-alarm and police systems; also for phonographs, electric clocks, medical coils, railway signal apparatus, electric fans and for laboratory purposes. They are largely used for supplying current to operate automobiles, and also as a source of power in launches designed for lake and river use.

Street cars and electric locomotives are being operated by current from storage batteries carried thereon, with varying degrees of success, and in train lighting, yacht lighting and carriage lighting they have been applied to some extent. Electric elevators, dental motors, automatic pianos, heat regulators and X-ray apparatus obtain the necessary current in many cases from storage cells, and they have also been employed for electric welding, electroplating and electrotyping.

For country residences and other buildings situated at a distance from a central station generating electricity, storage cells in connection with a dynamo run by a gas or oil engine, or by small water power, afford a means of independently and conveniently storing up electricity for lighting or power purposes by simply running the dynamo once or twice a week to keep the battery charged.

In electric plants of large office buildings, storage cells find an immense field of application, for in the majority of these the engines and dynamos may be shut down at night and the storage battery made to supply the necessary current for

lighting and elevator purposes. During certain parts of the day when the load on the machines is light, the battery can be charged, and at other times of the day when the load becomes extra heavy the battery can be called into service and thus made to help out the generators during the critical periods.

For central station work, storage cells are largely employed in much the same way as in the case of large office buildings just mentioned. Among the advantages arising from their use when thus employed may be mentioned the reduction in coal consumption and the lower operating expense resulting from the shutting down of the machinery during periods of light loads; also, the feasibility of running the machinery at full load, and therefore at its highest efficiency, while in service. When storage cells are used in central stations for helping out the generators during short periods of extra heavy load, these cells serve in place of additional generators that would otherwise be necessary, and a considerable saving in the generating equipment is thereby effected. By the aid of storage cells a better regulation of voltage during variations in load, such as those caused by street cars or elevators, is obtainable, than would be the case if the cells were not installed.

123. Show by means of a diagram how a storage battery helps the generators in a central station.

The diagram which best illustrates this case is a curve which shows the current delivered throughout twenty-four hours by the respective generators and storage cells in a direct-current lighting station. Such a curve is shown in Fig. 18 and is called a load curve.

Each division on the horizontal line represents one hour, and according to the numbers thereon the curve covers twenty-four hours, from 12 A.M. of one night to 12 A.M. of the following night. Each division on the vertical line represents 50 amperes, the limiting values being 0 amperes and 2,100 amperes. At any given time, therefore, the length of a line

from the corresponding point on the horizontal base line to the curve, as measured on the vertical line of amperes, represents the number of amperes generated. The shaded spaces denote the number of ampere-hours of work done by the generators in charging the battery and the number of ampere-hours of work done by the battery in helping out the generators; the former quantities are represented in Fig. 18

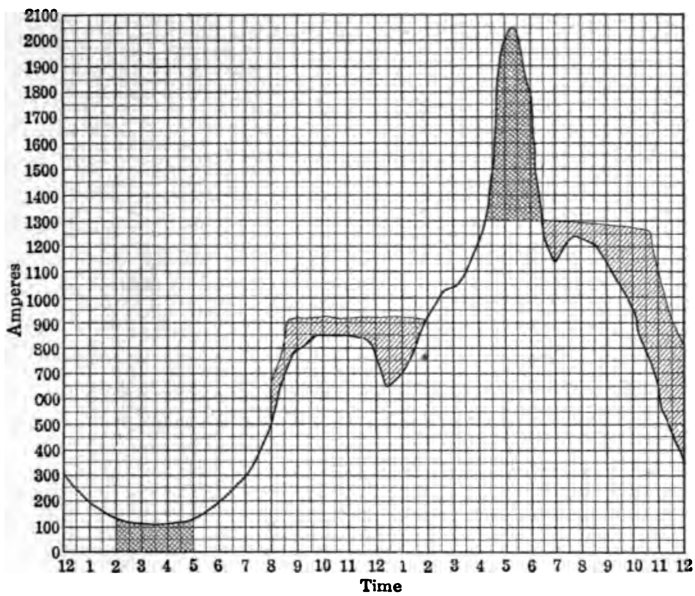


Fig. 18.—Load Curve of Central Station equipped with Storage Cells and Generator.

by single cross-hatching, and the latter quantities are represented by double cross-hatching.

It is thus seen that at 12 A.M. of the first night the generators were carrying a load of about 300 amperes; that this load gradually decreased as the night wore on until at 2 A.M. it was only 125 amperes. It was deemed advisable then to shut down the generators and allow the battery to carry the load until 5 A.M.; during this time whatever cleaning or re-

pairing of the generators or engines that was needed was done. As the load began to increase at 5 A.M., the generators were again started and carried the load until 8 A.M., when in addition to the current they were supplying to the line, somewhat over 100 amperes were switched into the battery for charging it. The charging process was continued until 2 P.M., at which time it was found that the battery was fully charged. As shown by the curve, the load was then increasing quite rapidly, and it continued to do so until shortly after 4 P.M., when the battery was again called into service and made to carry that portion of the load above 1,300 amperes. The maximum load of 2,050 amperes occurred at 5.15 P.M., at which time the battery was helping the generators to the extent of 750 amperes. The peak of the load, or that number of ampere-hours represented by the double cross-hatching at this part, was supplied by the battery. At 6.30 P.M., however, the load had dropped sufficiently for the generators to easily carry it, and as it continued to decrease, the extra current from the generators was used in recharging the battery. The load continued to diminish and the charging process was maintained during the remainder of the twenty-four hours.

124. What is the actual saving effected by the storage battery in the station just described?

Consider, first, what the generators would have had to do if no storage battery was employed. At 110 volts pressure, the generators would have had to develop $110 \times 2{,}050 = 225.5$ kilowatts, whereas with the battery they need only develop $110 \times 1{,}300 = 143$ kilowatts. Aside from the great reduction effected in generator capacity, and consequently in the first cost of the plant, the battery also provides sufficient time for the necessary cleaning and repairing of the moving machinery without interrupting the service.

125. Show by means of a diagram the regulating effect of a storage battery in an electrical station.

Referring to the diagram of Fig. 19, in which are plotted three curves, the divisions on the horizontal base line denote

periods of time for all three curves, each division representing 10 seconds. The divisions on the vertical line at the left represent the number of amperes for each of the three curves. The middle curve shows the periodic variations of the load on the station, supplied by a generator and storage battery.

The variations in the load are both rapid and sudden, the current jumping at times from 100 amperes to over 500 amperes in 5 seconds or less. If fluctuations of this nature

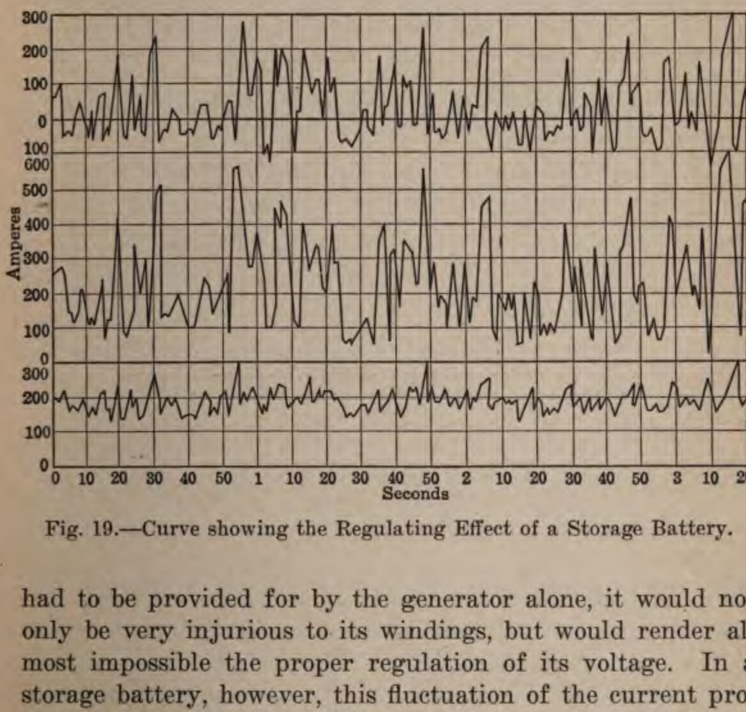


Fig. 19.—Curve showing the Regulating Effect of a Storage Battery.

had to be provided for by the generator alone, it would not only be very injurious to its windings, but would render almost impossible the proper regulation of its voltage. In a storage battery, however, this fluctuation of the current produces no injurious effect if its capacity be properly chosen.

In Fig. 19 the top curve represents the variations of current from the battery, and it is obvious that it follows very closely the various changes in the load. Thus when considerable current is wanted on the line, the battery curve is seen to rise, and when less than the normal amount is required,

the battery received the surplus from the generator for charging purposes.

The variation of current from the generator is shown by the bottom curve in Fig. 19. This curve, when compared with the other two, is seen to be much more regular, the average current being somewhat less than 200 amperes. When it is remembered that without the service of the battery the generator would be required to meet to the fullest extent every fluctuation represented by the middle curve in the diagram, it is seen what an important regulating effect a storage battery has upon the equipment of an electrical station.

126. Is the nickel-iron storage cell specially adapted for central station work?

No. The field of usefulness of this cell, owing to its light weight, compactness and strong construction, is in electric vehicles of all descriptions and for ignition and small lighting outfits. For central station work, the lead type of storage cell is preferable on account of its lower initial cost.

UNPACKING AND ASSEMBLING

127. What precautions should be observed in unpacking a new lead type storage cell?

Care must be taken in handling the various parts, because some of them are very liable to be broken or bent out of shape. Upon removing the wrappers, each part should be examined for breakage and then checked up with the list of contents to see that the full shipment has been received and unpacked.

The jar or tank should be washed clean and placed in position, after which the plates should be prepared for use. This consists in removing from them all dust and foreign matter that may have formed part of the packing. Such matter under ordinary conditions may be of sufficient resistance to do no harm, but it becomes more or less carbonized under the action of the acid, and is then a fairly good conductor capable of doing considerable damage if it accumulates be-

tween the plates. The easiest and most effective way of removing this matter from the plates is to use an air-bellows.

The positive and negative plates must then be assembled, together with their separators, within the jar, and the solution or electrolyte introduced. The charging process should be commenced immediately afterward, as the plates and separators are very sensitive to exposure at this time. It is better, if the battery solution or the charging current is not at once available, to leave the packing on the plates and separators and keep them in a dry room.

128. How should a lead plate storage battery be assembled?

When the plates are small and few in number the elements can easily be lifted into the jars by the aid of a strip of webbing 4 or 5 inches wide placed around the plates as in Fig. 20, and withdrawn when the plates are properly in position in the jar. If the plates are larger and more numerous, two S-shaped iron hooks caught around an element and looped over a rod carried by two men, will be found very convenient; but if the plates are very heavy and each element consists of a large number of them, a traveling crane should be employed.

In arranging the separate cells of a battery, care should be taken to so place them relatively to each other that the positive lug of one cell and the negative lug of the adjoining cell are together. This insures the proper polarity throughout the battery, bringing a positive lug or terminal at one free end and a negative lug or terminal at the other end.

129. What is the best method of connecting the cells of a storage battery together?

The lugs of adjoining cells may be connected together either by clamps or bolts, or they may be burned or welded together. The best method consists in welding, by means of a hydrogen flame, the two adjacent lugs to a lead strap of large cross-section; for very large currents a copper conductor may be embedded in this lead strap.

130. Are there any special precautions to be observed in connecting the cells together?

Before making connections with the lugs, they must be well scraped at the points of contact, so as to obtain good conductivity and low resistance between them. It is advisable to scrape the lugs before the elements are placed in the jars,

Fig. 20.—Placing the Elements in the Jar.

else the scrapings are apt to fall into the cells and cause trouble.

It is also well to bear in mind that when two dissimilar metals are joined together and become covered with a film of acid, local currents are liable to be developed between the

metals, which tend to impair their connection. For this reason it is preferable to avoid the junction of two different kinds of metals, but in case it is found necessary, the destructive action may be largely prevented by coating the metals thus connected with paraffin wax or with a sulphuric-acid-proof paint.

131. What are the ingredients of a sulphuric-acid-proof paint?

An excellent paint for this purpose may be made with wood naphtha colored with vermilion or lamp-black, and shellac. Of the two colored paints thus obtained, the red should be applied to all positive connections and the black to all negative connections, this being the usual rule, which, if followed, will be found to lessen the liability to mistakes in making connections.

132. How should the battery solution in a lead plate cell be prepared and tested?

Both the sulphuric acid and the water used to dilute it should be free from impurities. Special care should be taken that no metallic objects such as tools, bits of wire, etc., be allowed to remain in the solution.

In mixing, use one part by volume of acid with five parts by volume of water. Pour the acid slowly into the water; never pour the water into the acid as there will be excessive heating. Maintain the specific gravity of the solution at the density specified by the manufacturer, either by the addition of water or acid; and never let its temperature exceed 110 degrees Fahrenheit, preferably keeping it below 100 degrees.

133. How is the specific gravity of the solution measured?

By means of a hydrometer, Fig. 21, that consists of a graduated glass tube *a* of uniform diameter, a bulb *b* which is an enlargement of the tube, containing air, and in the bottom shot *s* which causes the stem to float in a vertical position.

The graduations on the stem range from 1.150 to 1.250, and whatever reading is obtained at the surface of the liquid indicates the specific gravity or density of the solution.

134. **How is the temperature of the solution measured?** By means of a Fahrenheit thermometer, graduated from 20 degrees to 130 degrees. The thermometer consists of a

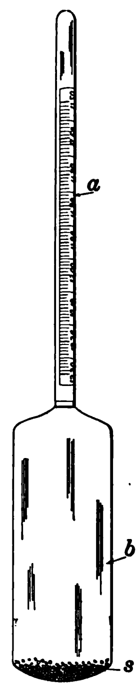


Fig. 21.—Hydrometer for Measuring the Specific Gravity of the Battery Solution.

graduated glass tube of small diameter, called the stem. This terminates in a bulb at the bottom, in which is mercury that expands with rise in temperature more rapidly than the glass and indicates by its height in the stem the temperature to which the bulb is subjected.

THE CHARGING PROCESS

135. Illustrate and describe the proper arrangement for charging a storage battery.

Connections are made as shown in Fig. 22, *b* representing the storage battery with its usual connections, *d* the charging generator and *m n* the main conductors of the circuit to be supplied by *b* or *d*, or by both *b* and *d* together. It should be noted the positive side of the generator is connected to the

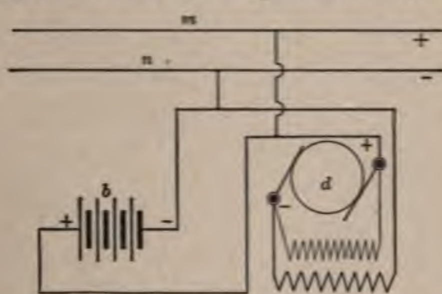


Fig. 22.—Connections for Charging Storage Cells.

positive side of the battery and also to the positive conductor *m;* the negative side of the generator is connected to the negative side of the battery and to the negative conductor *n*.

136. How may the positive terminal of the generator be determined?

Usually the most convenient method of determining which is the positive terminal and which the negative terminal of the generator is by use of a voltmeter. A voltmeter is an instrument for measuring the difference of potential or voltage of a circuit, and when this instrument is connected across the terminals of the battery alone, so that the pointer is deflected over the scale of the meter, the positive binding post of the meter will be that joined to the positive or brownish-colored plates of the lead type of battery; the negative binding post of the meter will be that joined to the negative or grayish-colored plates of the battery.

If, then, this voltmeter be connected across the terminals of the charging generator so that the pointer is deflected over the scale of the meter, the terminal connected to the positive binding post of the meter will be positive and the other terminal will be negative. The voltmeter used in this test should have a capacity slightly in excess of the rated voltage of either generator or battery.

Another method of determining the polarity of a generator or battery consists in connecting the terminals of either to two pieces of lead or other metal immersed in acidulated water. The passage of the current will cause bubbles of gas to form at both pieces, but the greater quantity of bubbles will appear at the piece connected to the negative terminal of the battery or generator.

137. What relation should exist between the voltage of the charging generator and that of the battery?

The rated voltage of the generator should be at least 50 per cent. above the normal voltage of the battery. In calculating the normal voltage of the battery, two volts may be allowed for each cell. The generator should be of the direct-current type.

If the voltage of the charging generator is such that there is any doubt of its being less than that of the battery when fully charged, an automatic switch should be introduced in circuit between them. This switch will protect the direct-current generator from running as a motor and possibly harming itself, by opening automatically in case the voltage of the battery becomes sufficiently high to send a reversed current through the machine.

In central station practice where the charging generator must supply current at constant voltage to the lines, simultaneously with the charging of the battery, arrangements must be made for obtaining two different voltages. If the voltage required on the line is large in comparison with that needed for the battery, the generator voltage may be regulated to that necessary for the line and an adjustable resistance in-

serted in the battery circuit for reducing the charging voltage. If, however, the voltage required by the battery is large in comparison with that needed on the line, an auxiliary generator called a "booster," driven either by the same power that drives the main generator or by an electric motor, may be used to provide the additional voltage necessary for charging the battery.

138. When should the charging process be commenced?

On new cells the charging process should not be commenced until the solution has had sufficient time to soak well into the separators employed; this requires from twelve to fifteen hours. In order to commence the charging process immediately after the plates have been unpacked, as previously directed in Answer 127, the separators should be soaked in the battery solution this length of time in advance.

139. How should the charging voltage be adjusted with respect to the battery voltage?

At the beginning of the charge, the voltage of the charging current should be adjusted from 2 to 5 per cent. higher than that of the battery cells; in other words, it should be such as to send through the battery cells the proper charging current.

The proper charging current depends largely upon the design of the plates, and as no two makes of cells are precisely alike, the value of the charging current will vary in different cases and should in every instance be obtained at the start from the manufacturer. Ordinarily, the normal charging current is about 8 amperes per square foot of the total surface of the positive plates per cell. Thus, if a cell contains five positive plates and six negative plates, each measuring 9 inches by 8 inches, or 72 square inches, the total surface of each positive plate will be $2 \times 72 = 144$ square inches, or 1 square foot. The total surface of the positive plates of the cell will therefore be $5 \times 1 = 5$ square feet, and at 8 amperes per square foot the charging current required will be $8 \times 5 = 40$ amperes.

Throughout the charging process the current should be kept normal, for if its value be exceeded the active material on the plates is seriously affected, and if it be less than one-fifth of the normal value, an insoluble sulphate is liable to form and injure the plates.

As the battery becomes charged its voltage rises, as shown in Fig. 23, and being opposed to that of the charging circuit it will be found necessary to increase the voltage of the gen-

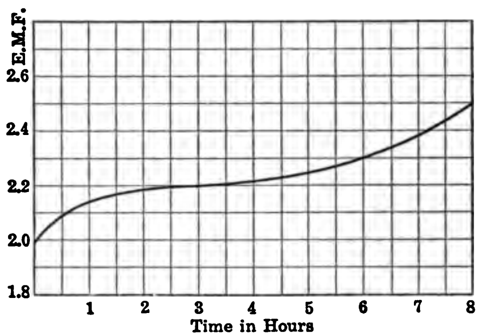


Fig. 23.—Curve showing how the Voltage of a Storage Cell increases during the Charging Process.

erator as the charging process advances, in order to maintain a constant value of the current. Just before the completion of the charge it may thus be found necessary to raise the charging voltage nearly 40 per cent. above the normal voltage of the battery.

140. Does any change occur in the specific gravity of the battery solution during the charging process?

During the first part of the charging process the specific gravity of the battery solution will decrease, but it should not be allowed to drop more than 0.005 from the standard density. Thus a cell having a normal density of 1.200 must not register below 1.195, its value being regulated by the addition of dilute acid or clear water, as the occasion demands. Instead of adding the acid or water directly to the battery solution, it is advisable to siphon off a portion of it and add a fresh

quantity having a higher or lower specific gravity, as the case may be.

In order to aid the battery attendant in estimating the quality and quantity of the solution to be added, the following figures are given to show the various specific gravities of the different combinations:

Per Cent. of Acid	Per Cent. of Water	Specific Gravity
50	50	1.398
47	53	1.370
44	56	1.342
41	59	1.315
38	62	1.289
35	65	1.264
32	68	1.239
29	71	1.215
26	74	1.190
23	77	1.167
20	80	1.144
17	83	1.121
14	86	1.098
10	90	1.068

After the charging process has advanced somewhat, the specific gravity of the solution will begin to increase and will continue to rise during the remainder of the charge, but should not be allowed to increase more than 0.005 above the standard density. Thus a cell having a normal density of 1.200 must not register above 1.205 on the hydrometer scale.

141. What should be done if the solution reaches too high a temperature?

If the temperature rises as high as 100 degrees Fahrenheit, it is advisable either to stop the charging process temporarily or to reduce the charging current until the temperature drops to about 80 degrees.

142. What determines the length of time required to charge a battery?

The length of time required to charge a storage battery depends upon the extent to which it has been discharged, and also upon the ampere-hour rate of the charging current. Or-

dinarily, it is not advisable to depart much from the rule previously given, which allows eight amperes per square foot of positive plate surface. In cases where no facilities are provided for keeping the charging current constant, this current, although it may be normal at the start, will afterward decrease and therefore require a longer time to complete the number of ampere-hours constituting the charge than it would were the charging current maintained at its normal value.

143. How is one to know when a charge is completed?

There are several ways by means of which one may know when a charge is completed. The voltage of a cell, when fully charged, is approximately known, being usually about 2.50 volts; the battery solution also takes on a milky appearance, caused by gas bubbles rising through the solution. This latter phenomenon is called "the boiling of the solution," although it does not result from a high temperature, as indicated by the term, but from the action of the gas bubbles previously mentioned.

144. Should all of the cells boil equally during the final stage of the charging process?

Preferably so, but it will often be found during this final stage of the charging process that certain of the cells boil more than others. This difference, however, does not indicate trouble unless in one or more of them there is no boiling whatsoever. Those behaving in this manner should be marked and temporarily disconnected from circuit when the battery is discharged, but they should again be introduced for the following charge in order that they average up well thereafter.

THE DISCHARGING PROCESS

145. What change in voltage takes place during the discharging process?

As a storage-battery cell discharges, the voltage drops, as shown in Fig. 24. In practice, it is not advisable to allow a cell to discharge below 1.8 volts with the current flowing at

normal rate, for, as shown by the curve, the voltage drops rapidly beyond this stage, and the plates are liable to become injured. The battery should therefore be recharged when the voltmeter indicates that the voltage per cell has dropped to practically this amount with normal current flowing. At

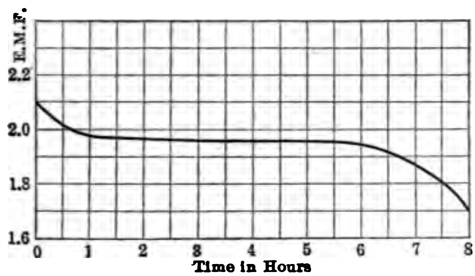


Fig. 24.—Curve showing the Gradual Drop in Voltage during Discharge of a Storage Cell.

higher than normal current rates, the limiting voltage is somewhat lower.

146. **What change occurs in the specific gravity of the solution during the discharging process?**

The specific gravity of the solution decreases as the discharging process advances, becoming less in direct proportion to the ampere-hours discharged. If it drops much below 1.175 on the hydrometer scale, it should be raised by replacing a portion of the solution with a fresh quantity having a higher specific gravity.

147. **What is the usual discharging rate of a storage cell?**

Ordinarily, the discharging rate of a storage cell should not be greater than 8 amperes per square foot of positive plate surface; its exact value, however, should be obtained in any given case from the manufacturer. The number of amperes which a cell is built to deliver continuously for eight hours is generally taken as a designating figure. Thus, a cell that will give 5 amperes for 8 hours is called a 40 ampere-hour cell. For a shorter period this cell will give continuously

a larger current, but the latter will not be larger in inverse proportion to the shorter period. Thus the 40 ampere-hour cell which gives 5 amperes for 8 hours will give about 7 amperes for 5 hours or about 10 amperes for 3 hours; in other words, it is really a 40 ampere-hour cell only at the normal 8-hour rate of discharge.

For central station work it is customary to provide a sufficient number of cells that the working voltage be obtained when all the cells are discharged to the safe limit—that is, to 1.8 volts per cell. Unless the installation is such that the load on the battery is greatest when the cells are fully charged and decreases as the battery discharges, the cells at one end are usually connected to a switch, so that a means may be provided for varying the number of cells in the working circuit at will.

148. Explain how an end-cell switch is used.

In a 110-volt installation, for example, there will be required at the beginning of a discharge about fifty cells. As the discharge progresses and the voltage drops, it will be necessary to adjust the end-cell switch so that an additional cell is introduced into circuit, and when the total pressure drops 2 volts more, another cell is switched in in a similar manner, and so on.

Owing to these end cells being in service a somewhat shorter time than those constituting the main battery, they do not become discharged to such an extent as do the others, and therefore require less time to be charged. At the beginning of the charging process an end-cell switch connects all the end cells with the others and permits the former to be cut out separately, first the one discharging for the shortest time, and then the others in the order of their discharge periods. Separate end-cell switches for the charging and the discharging processes are generally used to render it possible to have the battery permanently connected with the main circuit both while the cells are charging and while they are discharging.

DEFECTS AND REMEDIES

149. What is one of the more common troubles that occur in the operation of a storage battery?

Sulphating of the battery plates. This defect is caused by sulphate being deposited on the surface of the plates in the form of powder or scales. It may be detected by noting the appearance of the positive plates, which, if sulphated, become of a light grayish color; the entire surface of the plate may take on this color, or it may occur only in places. If this defect is not remedied, the active material of the positive plates will be loosened thereby and fall out. The grids are also liable to become decayed, and internal short-circuits result if the sulphating process is allowed to progress to an advanced stage.

150. How may sulphating of the battery plates be remedied?

Sulphating of the plates being generally caused by discharging the battery too quickly or too slowly, the remedy consists in taking care to discharge the battery at a normal rate. In most types of storage cells the normal discharging rate is, as stated in Answer 147, about 8 amperes per square foot of positive plate surface, although in every case it is best to consult the manufacturer in regard to this point.

Sulphating of the plates may also be caused by the battery solution being either too weak or too strong. If the deposit has been forming on the plates for some time, it may be necessary to scrape it off. In such a case the scraping should not be done by any metal, but by means of a stick. The plates should then be thoroughly washed, not with water, but with the battery solution, and directly afterward placed in the battery jars, which should preferably be refilled with fresh solution.

151. Is there any other trouble that the plates are subject to?

Unless separators of wood, glass or hard rubber are placed between the plates, they are liable to buckle or twist if the

battery is overcharged, and by coming in contact with each other short-circuit the battery. In modern types of storage cells separators are generally provided to prevent trouble in this way.

152. How may battery plates that have become buckled be remedied?

The plates should first be well cleaned and the entire set provided with boards, each having a thickness equal to the normal distance between the plates. The boards should be placed between the plates and pressure gradually applied to the outer ones until the plates regain their original shape. Under no conditions should a mallet be used in the straightening process, as any pounding on the plate will cause the blocks of paste to become loosened and fall out. After the plates have been straightened, future trouble from this cause may be obviated by a slow rate of charging and discharging, and by the use of separators between adjacent plates.

153. What is the average life of a storage battery?

The life of a storage battery for electric station service averages about four years, but it may be shortened considerably by improper use or neglectfulness. The active material in the positive plates succumbs first, but there is also a deterioration going on in the negative plates during the action of the battery.

154. What is one of the principal causes tending to shorten the life of a storage battery?

Internal short-circuits. Material thrown off from the plates collects in the bottom of the jar, and if allowed to accumulate will eventually come in contact with the lower parts of the plates and short-circuit them. Internal short-circuits shorten the life of a battery amazingly, and they may be caused not only by accumulations of plate deposits, as just mentioned, but by foreign substances such as nails, bolts or dirt accidentally getting in and lodging between the plates.

As it is customary to construct the battery so that the plates are supported above the bottom of the jar by lugs or ribs,

there is a space in which the foreign substances may collect for a time without short-circuiting the plates, but it is obvious that any deposit must be watched and cleaned out from time to time as occasion demands. Glass jars are particularly advantageous in facilitating inspections of the interior of the battery, although where battery jars which are not transparent are used a special form of 6 candle-power incandescent lamp having a flattened bulb and an elongated stem will be found very convenient in lighting up the interior for inspection.

155. What other causes tend to shorten the life of a storage battery?

Its life will be considerably shortened if the charging current be passed through the battery in the wrong direction. It is therefore necessary to make sure that the positive pole of the charging generator is connected to the positive pole of the battery, and that the negative poles are connected together, before the charging process is started.

Current leakage between the cells is also an important factor governing the life of a storage battery, and as this leakage may be such as to entirely discharge a cell without the knowledge of the attendant, it is advisable to guard against it as far as possible. If the cells rest upon iron rails, as is sometimes the case, the rails are liable to encourage any tendency there may be toward leakage. Then, too, if the jars are placed so closely together that they touch, or nearly touch, each other, there is liable to be leakage of current, because the battery solution always creeps more or less, and unless checked will form a conducting film on the outside of each jar. To prevent this a coating of melted paraffin wax should be applied with a brush around the inside of the battery jar to a depth of about an inch. Care should also be taken to slightly elevate the battery jars above the floor, else moisture will accumulate beneath them, and there being no chance for ventilation the conditions will grow from bad to worse, aggravating the conditions for leakage. Either plain por-

celain or glass insulating supports may advantageously be used beneath the cells to raise them above the floor.

156. What precautions should be observed when a storage battery is to be left unused for a few weeks?

The fact that storage cells gradually become discharged when allowed to stand idle, taken in connection with the deterioration of plates that occurs after the charge has decreased to a certain amount, renders it necessary to take certain precautions with cells that are to be left unused for a considerable time.

The precautions to take depend upon the length of time the battery is to be left out of commission. If it be but a few weeks, the plates may be protected from injury by introducing certain chemicals in the battery solution. Oxalic acid, potassium sulphate, sodium sulphate or caustic soda may be used for this purpose. In the case of caustic soda 1 ounce is sufficient for 5 gallons of the solution, although it is necessary to dilute the chemical to the extent of about 5 ounces of water to 1 ounce of caustic soda before adding it to the solution. When oxalic acid, sodium sulphate or potassium sulphate is used for this purpose, it should be diluted to the extent of 1 ounce of the solid material to 1 gallon of the solution. In dissolving sodium sulphate it is necessary to use hot water.

The chemical to be added should be introduced into the battery solution directly after the cells have been charged. Its introduction will cause a slight bubbling of the solution, and by neutralizing a small quantity of the acid will slightly reduce the specific gravity of the solution, which in turn will diminish the electromotive force of the battery to a small extent. Neither of these results is of a serious nature and need cause no apprehension.

157. What precautions are necessary when a storage battery is to be left unused longer than a few weeks?

The use of chemicals is not necessary, but the battery must be fully charged, after which the solution should be entirely

withdrawn and the cells filled with pure water. The battery should next be discharged, first through a resistance, and then when its voltage is nearly down, by short-circuiting the battery terminals so as to render the discharge complete. The plates must be allowed to soak in the water for about twenty-four hours, following which the water should be removed and the plates left dry in the jars.

The separators, if made of wood, will be found practically useless when the cell is again called into service, and may as well be thrown away; if, however, they are made of rubber, it is worth while to preserve them, so they should be washed in water and set aside with the plates.

158. What kind of apparatus will be found useful in operating a storage battery plant?

One or more hydrometers for measuring the specific gravity of the battery solution; a syringe or siphon for taking out the solution from the jars; a thermometer for measuring the internal temperature of the cells; a hydrometer jar for testing the specific gravity of the solution; a low reading direct-current voltmeter for measuring the voltage per cell; a high reading direct-current voltmeter for measuring the total voltage of the battery; a direct-current ammeter for measuring the charging current; the usual tools, such as pliers, wrench and screwdriver, common in other kinds of electrical work, and a battery inspection lamp of the electric incandescent type with flat bulb and long flexible wire connection.

159. What precautions should be observed by storage battery attendants for their own convenience and safety?

Sore hands is one of the most common inconveniences attending the care of a storage battery, being caused by the action of the battery solution on the flesh; this, however, may be remedied by occasionally dipping the hands into a supersaturated solution of washing soda and water.

The acid of the battery solution is also very destructive to clothing, but ammonia fortis will neutralize the acid and

prevent it from doing harm in this way if it be applied in time.

In siphoning the solution from a battery jar, an india-rubber tube is often employed; this is filled with the solution and the ends of the tube held closed until one extremity is placed in the battery jar and the other in the receiving vessel at a lower level. If, then, the ends of the tube be released, the solution will usually pass through the tube from the jar to the vessel without further assistance, but in some cases the suction is not sufficient and there may be a temptation to start the process by sucking the free end of the tube; this, however, must never be attempted, as the solution being both corrosive and poisonous would cause serious consequences if by chance some of it were drawn into the mouth.

Hydrogen gas is freely given off from the solution during the charging process, and this being of a highly explosive nature, the attendant is warned not to smoke while working about the battery, nor to carry a flame into the room while the battery is in operation.

160. Upon what factors should the selection of a given type of storage cell be based?

Upon its charge and discharge rate in hours, its ampere-hours per pound of weight, its watt-hours per pound of weight, its discharge in ampere-hours per dollar of cost, its discharge in watt-hours per dollar of cost and its discharge in watt-hours per pound of weight as compared with other standard types of storage cells.

In determining these factors the pressure readings should be taken with the voltmeter connected directly across the lead terminals of the cell, and not to the circuit or connectors. The current readings should be taken with the ammeter connected as closely as feasible to one terminal of the cell, so that any leakage of current may also be recorded. Ordinarily, about twenty readings furnish sufficient data for obtaining a good average value; if, however, the source of the current or the rate of discharge is unusually variable, or if the instruments

do not quickly respond to changes of current, it will be necessary to take a greater number of readings. A fairly accurate idea may be obtained of the condition of a storage cell before testing it, if its actual voltage on open circuit be obtained and compared with its rated value.

From the values obtained in the test, the following efficiencies may also be calculated and used as a basis of comparison in deciding upon a given type of storage cell.

$$\text{Ampere-hour efficiency} = \frac{\text{Discharge in ampere-hours.}}{\text{Charge in ampere-hours.}}$$

$$\text{Mean volt efficiency} = \frac{\text{Mean volts of discharge.}}{\text{Mean volts of charge.}}$$

$$\text{Watt-hour efficency} = \frac{\text{Discharge in watt-hours.}}{\text{Charge in watt-hours.}}$$

MAGNETISM

PERMANENT MAGNETS

161. What is a magnet?

A body usually composed of iron or steel that possesses the property of attracting other pieces of iron or steel.

162. Are there different kinds of magnets?

Yes, there are natural magnets and artificial magnets, but the latter kind are the only ones of practical use. Artificial magnets may be either permanent magnets or electromagnets.

163. What is the difference between a natural magnet and an artificial magnet?

The natural magnet is a species of iron ore and is called loadstone or magnetite. It was first found by the ancients at Magnesia in Asia Minor, and on account of its property of attracting pieces of iron was given the name of magnet by them.

If a bar of hard steel be rubbed a number of times in the direction of its length by a piece of loadstone, it will acquire the magnetic property of the natural magnet and to a much greater extent. The steel magnet thus formed is called an artificial magnet, and unless subjected to rough usage, such as sudden jars or high temperatures, will retain its magnetic properties for a considerable length of time. The harder the steel, other conditions being the same, the longer will it remain magnetized—but the more difficult also will be the process of magnetizing it. A bar of soft iron may be magnetized in a much shorter time than a bar of hard steel or nickel, but the latter will retain its magnetism for a much longer period.

164. Can artificial magnets be made in any other way than described in Answer 163?

Yes, instead of rubbing with a piece of loadstone, an artificial magnet already made may be used. Another method consists in wrapping around the steel bar a coil of insulated wire and allowing a current to flow through the wire for a time. When the bar is withdrawn from the coil it will be found permanently magnetized.

165. Is an artificial magnet, formed as described in Answers 163 and 164, a permanent magnet or an electro-magnet?

A permanent magnet.

166. Illustrate and describe the magnetic effect of a permanent magnet on iron filings.

Iron filings, being light in weight, afford the best means of exhibiting the property peculiar to magnets. If a handful

Fig. 25.—Iron Filings on a Permanent Bar Magnet.

of them be scattered over a permanent bar magnet, they will be attracted to the ends of the bar and will adhere thereto in great quantities; whereas, at or near the center of the bar there will be few, if any, filings observable.

This experiment is illustrated in Fig. 25, and goes to prove that the force of attraction is greatest at or near the ends of a magnet, that it decreases in strength as the center is approached from either end and that at the center of the magnet the force of attraction is zero. In speaking of a magnet, it is usual to designate the one end as a north pole, the other end as a south pole and its central portion as the equator.

167. How may the polarity of a magnet be determined?

The north pole of a bar magnet may be determined by suspending the magnet at its center, and if its support be sufficiently tortionless and frictionless, the north pole will always be at that end pointing toward the north. At the other end will be located the south pole of the magnet.

A simpler method, however, of determining the polarity of a magnet is by the aid of a compass, which is itself a magnet of light weight in the form of a needle or pointer freely supported at the center, so that it quickly takes up its position of rest in a north and south direction. The earth, constituting a huge magnet, with magnetic poles practically coincident with its geographical poles, exerts the directive influence. If one end of the magnet, whose polarity is to be determined, be held near the end of the compass needle pointing toward the north, one of two things will take place: either the north pole of the compass needle will be attracted to the end of the magnet presented or it will be repelled from this end of the magnet. Either of these actions, taken in connection with the fact that like magnetic poles repel each other, and unlike magnetic poles attract each other, provides an easy method of ascertaining which is the north pole and which the south pole of the magnet. If repulsion ensues, the end of the magnet presented is a north pole and the other end of this magnet is a south pole; whereas, if attraction takes place, the end of the magnet presented is a south pole and the other end a north pole.

The simplest method of determining the polarity of a magnet is by testing it with one whose polarity is already known. By simply holding the ends of the two magnets near each other, either the attractive force exerted between the two will be easily felt or there will be a repulsion, which, however, is not usually so easily detected. This method is a simple modification of the compass-needle method just described, and conclusions regarding polarity are formed in a similar manner.

168. Is it possible for a magnet to have a north pole without also having a south pole?

No; the two are inseparable. If a magnet, *m*, Fig. 26, were to be broken into any number of pieces, *h*, *l*, *v*, with the intention of separating the two poles, it would be found upon testing the polarities of these pieces that each of them would be a magnet complete in itself, with a north pole *N* at one

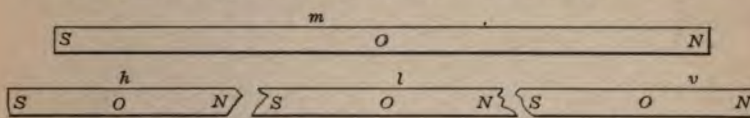


Fig. 26.—Distribution of Magnetism in a Bar Magnet when Broken.

end, a south pole *S* at the other end and a neutral point *O* at the equator.

169. Explain the principle upon which a magnet attracts iron filings.

The principle underlying the magnetic attraction of iron filings or other pieces of iron or its alloys is called magnetic induction; that is to say, when the north pole of a magnet is brought near an unmagnetized piece of iron, the latter, although itself possessing no magnetism, becomes magnetized by induction, even though there be no contact between the two. A north pole is thus induced or caused to exist in that end of the piece of iron further from the north pole of the magnet, and as a north pole cannot exist alone in the iron, the accompanying south pole appears at its nearer end. Since unlike poles attract each other, there will be a tendency for the south pole of the iron and the north pole of the magnet to come together. Whichever of the two attracting metals is the lighter and the more free to move will naturally tend to travel toward the heavier one offering the higher resistance.

Applying a similar line of reasoning in the case of a south pole, it is seen why each of the minute iron filings in Fig. 25, which temporarily becomes a magnet by induction, travels

toward the one or the other of the two poles of the magnet and adheres to it as shown. The filings remain magnetized only so long as they are under the influence of the poles of the magnet; as soon as they are separated therefrom and placed at a distance, they lose whatever magnetic properties they previously possessed.

170. How is the inductive action just described, assumed to travel?

In a definite direction, and along imaginary lines called lines of force. These lines, although invisible, are assumed to pass out in all directions from the north pole of a magnet,

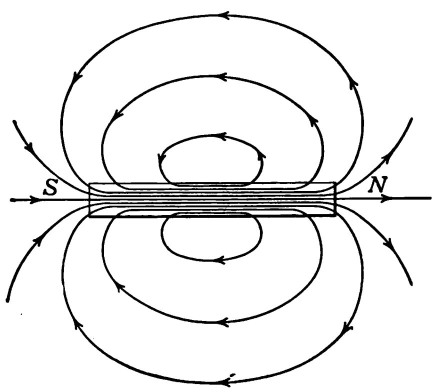


Fig. 27.—Magnetic Lines of Force of a Bar Magnet.

make complete circuits through the surrounding space and return into the south pole of the magnet, passing thence through the magnet to their starting points at the north pole. Lines of force are never straight and never intersect each other, but are curved and symmetrical as shown in Fig. 27.

The greater the number of lines of force provided by a magnet, the stronger its magnetic action. The number of lines of force passing through a unit of area, as a square inch, is a measure of the magnetic strength of a magnet and is called the " magnetic density " or the " flux " per square inch. The space surrounding a magnet which is permeated

with the lines of force is known as the "field" of the magnet.

171. What substances can be attracted by a magnet?

Only those substances which are themselves capable of becoming magnetized. Of these, iron and steel are the most sensitive, although nickel, cobalt, manganese, cerium and chromium are also classed as magnetic substances. All other substances are incapable of becoming magnetized, hence cannot be attracted by a magnet, and are therefore called non-magnetic substances.

172. Describe the effects which result from interposing sheets of magnetic material and sheets of non-magnetic material between a magnet and the iron that it is attracting.

Sheets of non-magnetic material, such as glass, brass, paper, etc., offer no more resistance to the passage of the lines of force through them than does the same air space; consequently, the attractive force of the magnet is not diminished thereby in the least.

If sheets of magnetic material such as iron or steel be placed between a magnet and the iron that it is attracting, the lines of force will complete their circuits through the iron or steel in preference to passing beyond, for the reason that the magnetic material of the sheet offers a path of lesser resistance than does air; consequently, the attractive force of the magnet will not extend beyond the magnetic screen thus formed.

173. According to what rule may the force exerted between two magnetic poles be estimated?

By this rule, namely:—The force exerted between two magnetic poles is proportional to the product of their pole strengths, and is inversely proportional to the square of the distance between them.

174. What is a horseshoe magnet?

A horseshoe magnet is simply a modification of the bar magnet; in fact, is a bar magnet with its ends bent around in the shape of a horseshoe, as shown in Fig. 28.

The advantage gained by this change in shape is the increased magnetic flux between the poles N and S, owing to the shorter path through the air and the consequent decreased

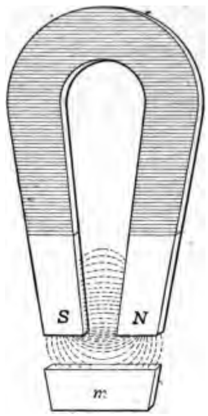


Fig. 28.—Permanent Horseshoe Magnet and Keeper.

resistance to the lines of force. In this form the permanent magnet is often found to be very serviceable, and can be made to exert considerable pulling force by bolting a number of them, separately magnetized, together with like poles touching each other.

To aid the horseshoe magnet in retaining its magnetism, a soft iron armature, or keeper m, Fig. 28, is used to close the gap between the poles when the magnet is not in use.

ELECTROMAGNETS

175. What is an electromagnet?

An electromagnet is a bar of soft iron which may be straight, but more commonly in the shape of a horseshoe, which is magnetized by the passage of a current through a coil of insulated wire wound around it and which ceases to be magnetized when the current ceases.

The wire composing the coil is wound in opposite directions around the limbs or straight portions of the horseshoe magnet, as shown in Fig. 29, to produce poles of opposite

polarity at the ends. The portion *c* joining the limbs *a* and *b* is called the yoke of the magnet.

176. **Is there a definite relation between the directional flow of the current around the magnet and the resulting polarity?**

Yes; when the current travels around the core or limbs of a magnet in the direction taken normally by the hands of a clock, the north pole will be at the end further from the observer, leaving the south pole at the nearer end. This case is illustrated in Fig. 29 by considering the left-hand leg

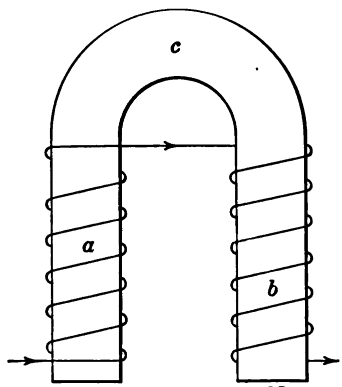


Fig. 29.—Electromagnet.

a; the current is traveling through the wire as indicated by the arrows, and a south pole is formed at *S*. When the current travels around the core in the opposite direction to that taken normally by the hands of a clock, the north pole will be at the end nearer the observer, leaving the south pole at the further end. This case is also illustrated in Fig. 29 by considering the right-hand leg *b* with the north pole developed at *N*.

177. **What factors govern the magnetizing power of an electromagnet?**

The magnetizing power of an electromagnet, or magnetomotive force, as it is frequently termed, is proportional to the

number of amperes flowing through the magnet winding and the number of turns of wire on the magnet core. Two amperes flowing through 10 turns of wire will therefore give the same magnetizing power as 10 amperes flowing through two turns, or 1 ampere flowing through 20 turns.

If $c =$ the number of amperes, n the total number of turns on the core, 1.257 a constant and $M.M.F.$ the magnetomotive force in gilberts (1 gilbert being equal to 0.7958 ampere-turns), then $M.M.F. = 1.257\ c\ n$.

178. Calculate the number of gilberts of magnetomotive force in an electromagnet composed of 96 turns through which a current of 2 amperes is flowing.

According to the problem the number of amperes $c = 2$, and the number of turns $n = 96$. Substituting these values in the formula $M.M.F. = 1.257\ c\ n$, there results $M.M.F. = 1.257 \times 2 \times 96 = 241.344$; 241.344 gilberts is therefore the magnetomotive force, or magnetizing power of the electromagnet.

179. How are the magnetic qualities of iron and steel best represented?

By curves of magnetization such as shown in Fig. 30 for sheet iron annealed, cast steel unannealed, wrought-iron forgings, and gray cast iron, respectively. By means of these curves it is possible to find at a glance the magnetizing force or the number of ampere-turns per inch of length necessary to employ in the case of any of these magnetic substances for obtaining a given magnetic density in lines of force per square inch of sectional area.

Thus, to cause 115,000 lines of force per square inch through sheet iron annealed requires, according to the magnetization curve for this material, 500 ampere-turns per inch of length; to cause 80,000 lines per square inch through cast steel unannealed requires 150 ampere-turns per inch of length; to cause this same magnetic density in wrought-iron forgings requires 100 ampere-turns per inch of length; and to cause

55,000 lines of force per square inch through gray cast iron requires 550 ampere-turns per inch of length.

180. In what respects do the calculations in a magnetic circuit resemble those in an electrical circuit?

In an electrical circuit, according to Ohm's law, the current flowing is equal to the electromotive force divided by the resistance. In a magnetic circuit the total number of lines of force flowing is equal to the magnetomotive force divided by the reluctance. The reluctance of a magnetic circuit corresponds, therefore, to the resistance of an electrical circuit, and it increases as the length of the magnetic circuit increases, decreases as the sectional area of the magnetic circuit increases, and decreases as the permeability or conducting power of the magnetic circuit for lines of force increases.

181. Calculate from the magnetization curve for wrought iron given in Fig. 30, the number of turns required in a magnet supplied with 2 amperes of current, to produce a flux of 180,000 lines of force in a core of this material 2 square inches in sectional area and 10 inches in length.

The required magnetic density per square inch, according to the problem is $180{,}000 \div 2 = 90{,}000$ lines of force. According to the curve for wrought iron in Fig. 30, it requires 200 ampere-turns per inch of length to produce this magnetic density. As the core is 10 inches long, $10 \times 200 = 2{,}000$ ampere-turns will be necessary in the magnet coil. Since the current at hand is, according to the problem, 2 amperes, the number of turns required will be $2{,}000 \div 2 = 1{,}000$.

182. What relation exists between the permeability of a magnetic substance, its magnetic density per square inch, and its magnetizing power in ampere-turns per inch of length?

The permeability of a substance is its magnetic density per square inch divided by its magnetizing power in ampere-turns per inch of length. If, therefore, a number of corresponding values of the magnetic density and magnetizing force be found from any one of the curves given in Fig. 30, and divided as

just stated, the quotients will be the values of the permeability for the respective values of the magnetic density corresponding to the substance represented by the curve. The results

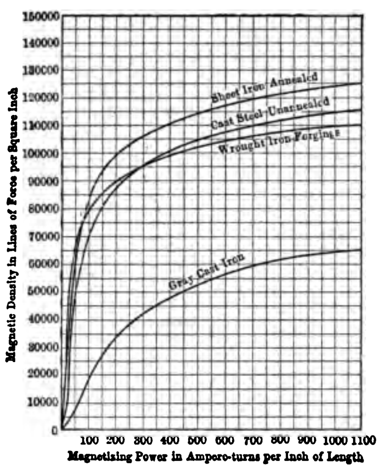


Fig. 30.—Magnetization Curves.

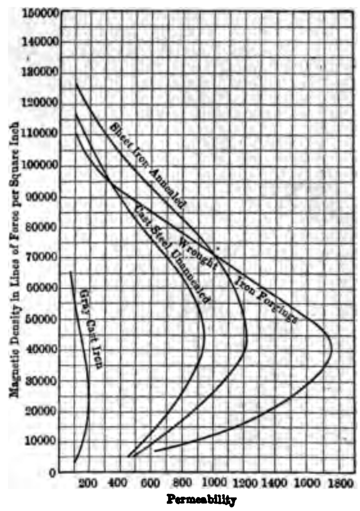


Fig. 31.—Permeability Curves.

thus obtained from the curves in Fig. 30 will, if plotted, give the permeability curves shown in Fig. 31.

183. State the formula for calculating the reluctance of a magnetic circuit to a given magnetic density.

The formula is $r = \frac{l}{\mu a}$, in which $l =$ the length in inches of the magnetic circuit, $a =$ the cross-sectional area in square inches of the magnetic circuit, $\mu =$ the permeability of the material composing the circuit and corresponding to the given magnetic density, and $r =$ the reluctance of the magnetic circuit.

184. Calculate the reluctance of a cast-steel magnetic circuit 7 inches long and 50 square inches in cross-section corresponding to a magnetic density of 70,000 lines of force per square inch.

According to the problem, the length of the magnetic circuit $l = 7$, the cross-sectional area $\alpha = 50$ and from the curve for cast steel in Fig. 31 a magnetic density of 70,000 lines gives $\mu = 700$. Substituting these values in the formula $r = \frac{l}{\mu\alpha}$, there results $r = \frac{7}{700 \times 50} = 0.0002$. The reluctance of the circuit is therefore 0.0002.

185. Determine the number of turns necessary for a coil carrying 3.5 amperes to maintain the conditions specified in Question 184.

The total number of lines of force required is $50 \times 70{,}000 = 3{,}500{,}000$, and the reluctance is 0.0002. According to the information given in Answer 180, the magnetomotive force is equal to the reluctance multiplied by the total number of lines of force flowing. In the present case the magnetomotive force is therefore that due to $0.0002 \times 3{,}500{,}000 = 700$ ampere-turns. With 3.5 amperes of current in the coil, the necessary number of turns will therefore be $700 \div 3.5 = 200$.

186. What is residual magnetism?

The magnetism remaining in a magnetic substance after it has been removed from a magnetic field. It is owing to this property that artificial magnets retain their magnetic strength for so long a time. As stated in Answer 163, hard steel and nickel retain their magnetism for a much longer time than does soft iron, and they may therefore be said to possess more residual magnetism.

187. Explain what is meant by magnetic leakage.

Magnetic leakage is the straying of the lines of force from their main path, and is due to the existence of other paths offering usually a lower magnetic resistance or reluctance. Leakage may, however, occur into the surrounding air space, which, although of higher reluctance than iron or steel occupying the same amount of space, is at the same time a magnetic conductor having a permeability of 1; in cases where the air space provides a shorter and easier path for

certain of the lines of force than is afforded them by the main magnetic circuit, leakage results.

Those lines of force which are thus led astray produce no useful work, and in the design of a magnet every effort should be made to reduce this loss to a minimum. With this object in view, the iron or steel used in the magnetic circuit should possess a high permeability, the length of the magnetic circuit should be as short as practicable under the attending conditions and the cross-sectional area of the magnetic circuit should be comparatively large and as uniform as possible.

188. Aside from the leakage of lines of force, are there any other internal losses that may occur during the magnetization of a piece of iron?

Yes, there is a hysteresis loss and an eddy current loss.

Hysteresis is a lagging or retardation of the magnetic effect when the lines of force are reversed in rapid succession by changing the direction of the magnetizing current. This effect is due to a magnetic friction within the core and causes the iron to become heated, thereby occasioning a loss of energy. The softer the iron and the smaller the magnetizing current, the lower will be the hysteresis loss.

Eddy currents are useless local currents in an iron core, caused by the electromotive forces developed by its motion through a magnetic field or by a varying current nearby. They are of greatest intensity when the changes in the magnetic field or the current are the greatest and most sudden. Eddy currents cause a loss of energy by heating the iron core, and they may cause it to become so hot as to char the insulation of its windings. These currents may be prevented by laminating or dividing the core so as to impose resistance in their path; that is, the core should be built up of thin sheets of iron insulated from one another by a coating of japan or varnish and pressed together, rather than composed of a solid mass of metal.

PRACTICAL APPLICATION OF MAGNETS

189. State the principal advantage which electromagnets possess over the other types of magnets previously mentioned, for practical applications.

Electromagnets are best adapted to most practical purposes for the reason that it is possible to exercise complete control of their magnetism and therefore of their action. When the magnetizing current is flowing through the turns of the magnet coil, the core is magnetized and attracts the armature. At the instant this current is stopped, however, the magnetic effect ceases and the armature is free to be drawn away from the magnet poles either by a spring or by the force of gravity. Inasmuch as the circuit in which the magnet coil is connected, and through which the magnetizing current flows, can be closed or opened at will from almost any distance, the action of the electromagnet is under perfect control from any desirable position.

190. Mention the more common applications of electromagnets to commercial purposes.

Electric bells, electric clocks and telegraph instruments; also as field magnets on electric generators and motors.

191. Give the formula for finding the pull or lifting power of a magnet.

The formula is $p = \frac{B^2\ a}{72{,}134{,}000}$, in which $a =$ the total area in square inches of contact surface, $B =$ the magnetic density in lines of force per square inch, and p the lifting power in pounds.

For lifting or tractive work the horseshoe type of electromagnet is invariably employed, and as there are then two contact surfaces, one at the north pole and the other at the south pole, the total number of lines of force developed are used twice in causing the traction. If the contact surfaces are each equal in area and are symmetrical, the total lifting power will be twice the amount found by the formula for each con-

tact surface alone; otherwise, the lifting power for each contact surface should be calculated separately and then added together for the total amount.

192. Calculate the total pulling effort of a magnet, each core of which has an area of 10 square inches and a magnetic density of 110,000 lines of force.

According to the problem the magnetic density $B = 110{,}000$, and the core area $a = 10$. Substituting these values in the formula $p = \frac{B^2\ a}{72{,}134{,}000}$, there results $p = \frac{(110{,}000)^2 \times 10}{72{,}134{,}000} =$ 1,677 pounds. The two poles of the magnet will therefore exert a total pulling effort of $2 \times 1{,}677$ pounds, or 3,354 pounds.

193. Give the formula for finding the magnetic density in lines of force per square inch necessary to develop a certain pulling effort with a given area of contact surface.

This formula may be obtained by transposing the factors in the formula given in Answer 191 so as to obtain an expression for B in terms of p and a. Thus if $p = \frac{B^2\ a}{72{,}134{,}000}$, then $B =$ $8{,}493\sqrt{\frac{p}{a}}$.

194. Calculate the magnetic density in lines of force per square inch necessary to employ in an electromagnet where it is desired to have each pole exert a pulling force of 400 pounds, the area of contact being 4 square inches.

According to the problem the pulling force $p = 400$, and the core area $a = 4$. Substituting these values in the formula $B = 8{,}493\sqrt{\frac{p}{a}}$, there results $B = 8{,}493\sqrt{\frac{400}{4}} = 84{,}930$. The necessary magnetic density to employ is therefore 84,930 lines of force per square inch.

195. Give a formula for finding the portative power of a permanent magnet—that is, its capability of holding up or carrying a weight.

The formula is $w = 20.7\ \sqrt{t^3}$, in which $t =$ the weight of the magnet, and $w =$ the weight which the magnet can carry.

The portative power of a magnet may, however, be increased by gradually applying the load on its armature day by day; in this way it may be made to carry a load which at the beginning of the process it could not have borne. If the load be thus gradually increased until the armature falls, the portative power of the magnet decreases at once to its original value.

196. Calculate the portative power of a steel magnet weighing 4 pounds.

According to the problem, the weight $t = 4$. Substituting the value in the formula $w = 20.7\sqrt{t^3}$, there results $w = 20.7\sqrt{64} = 165.6$. The portative power of the magnet is therefore 165.6 pounds.

ELECTROMAGNETIC INDUCTION

197. What is electromagnetic induction?

The production of electric currents in a wire due to changing magnetic conditions with respect to the wire.

198. Describe the method of producing a current of electricity by electromagnetic induction.

The method can best be described by aid of the illustration, Fig. 32, in which the ends of two wires are shown at *c* and *e*,

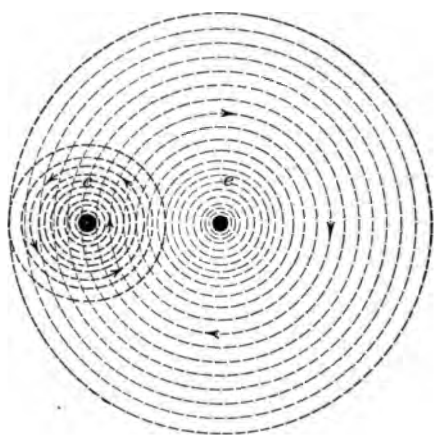


Fig. 32.—Illustrating the Principle of Electromagnetic Induction.

respectively. The dotted circles represent the magnetic lines of force surrounding these wires when a current of electricity is flowing through each of them. If the current in the wire *e* be flowing from the observer and that in the wire *c* be flowing toward the observer, the direction of travel of the lines of force in the two cases will be as represented by the arrowheads.

In order to satisfy the conditions shown in Fig. 32, it is simply necessary that the wire *e* be connected to a source of current; if, then, the wire *c*, having its ends joined together so as to form a closed circuit, be brought into the magnetic field of the wire *e*, an electromotive force will be induced in the closed circuit which will cause a current of electricity to flow through it. The inductive action is caused by the wire *c* cutting the lines of force as it is brought into the field of the wire *e*.

The electromotive force induced in *c* is directly proportional to the rate of cutting the magnetic lines of force, and therefore depends upon the number of lines of force developed by the current in *e*, and the velocity with which *c* is brought into the magnetic field of *e*, being higher as the values of these two quantities are increased.

199. What direction of flow has the induced current relatively to the current producing the action?

The current induced in the wire *c*, Fig. 32, as it is brought into the field of the wire *e*, flows in the opposite direction to that in the wire *e*. The direction of travel of the lines of force resulting from the induced current is therefore opposite to that of the lines of force of the inducing current; the former lines consequently oppose the latter, as represented by the arrowheads in Fig. 32, and tend to stop them.

On the other hand, when the wire *c* is withdrawn from the field of the wire *e*, the induced current in *c* is reversed, reversing in consequence the directional flow of its lines of force.

200. In what other way besides that already mentioned may electromagnetic induction be illustrated?

By making and breaking the current in the wire *e*, currents will be produced by electromagnetic induction in the wire *c*, even though it be permanently located in the field of *e*. When the current commences to flow through the wire *e*, the establishing of the magnetic field surrounding this wire causes the magnetic lines of force constituting its field to cut the

wire *c*. Inasmuch as the electromotive force, and therefore the current induced in *c*, depends solely upon its rate of cutting the lines of force, the result will be the same as when the wire *c* was brought into the already established field of the wire *e*, if the current in *e* be equal in both cases and the lines of force cut the wire *c* with the same velocity as the wire *c* was made to cut the lines of force in the former case.

Similarly, when the current ceases to flow through the wire *e*, the collapsing of the lines of force surrounding the wire *e* will produce in *c* a current which will flow in the opposite direction to that caused by the current in *e*, when starting.

In any case the lines of force developed by the induced current in the wire *c* will travel around *c* in such a direction that their reaction or magnetic effect will tend to stop the motion producing them; that is, to stop the motion of the lines of force developed by the current in the wire *e*.

201. What are the important factors which govern the production of electricity by electromagnetic induction?

Motion is an important factor, inasmuch as the electromotive force and therefore the current induced depend upon the rate of cutting the magnetic lines of force. If, for example, the current in *e* be maintained at a constant value after it has been started, the current induced in *c* at the start will then cease to flow. The reason for this is that the lines of force surrounding *e* will remain stationary, and as the wire *c* is also stationary, it is neither cutting nor cut by lines of force and consequently no current is induced therein.

By winding upon an iron core that portion of the insulated wires of the two circuits which are subjected to inductive action, the effects will be greatly increased over those obtainable from straight parallel wires as in Fig. 32.

202. Give the usual terms applied to apparatus in commercial use whose operation is based upon electromagnetic induction, and also the terms by which the two circuits therein are designated.

Every dynamo or commercial machine generating electricity operates by virtue of electromagnetic induction. Usually, the stationary circuit carrying the inducing current is called the field circuit, and the moving circuit in which the current is induced is called the armature.

In the induction coil, an electromagnetic induction device largely used in medical work, the inducing circuit is called the primary circuit, and the circuit in which current is induced is called the secondary circuit. Both circuits are stationary, but the lines of force of the primary circuit are made to cut the secondary circuit by alternately making and breaking the primary current in rapid succession.

In alternating-current work there is the transformer, a piece of apparatus constructed similarly to an induction coil, for producing from a given electrical current another current of different voltage by means of electromagnetic induction. In this case the primary and secondary circuits are stationary as in the induction coil, but instead of alternately opening and closing the primary circuit, the rapid reversals of the alternating current keep the lines of force cutting the turns of the secondary coil and induce in them an electromotive force which bears the same proportion to the primary electromotive force as the number of turns in the secondary coil bears to those in the primary coil. In each of these electromagnetic induction devices, the insulated wires or conductors constituting the active portions of the two circuits are wound upon iron cores to increase the effects as previously mentioned.

203. What action takes place when two magnetic fields are brought together so that the lines of force of the one intercept those of the other?

There is a tendency for the lines of force to arrange themselves so as to coincide in direction and thereby cause motion to the magnetic bodies producing the fields. This action can best be explained by reference to Fig. 33, where *N S* represents a compass needle having a north pole at *N* and a south

pole at *S*, and *c* a wire through which a current is flowing in the direction of the arrow *a*.

The magnetic lines of force developed by the needle, it will be remembered, complete their circuits through the air by passing outside the needle from *N* to *S*, while those developed

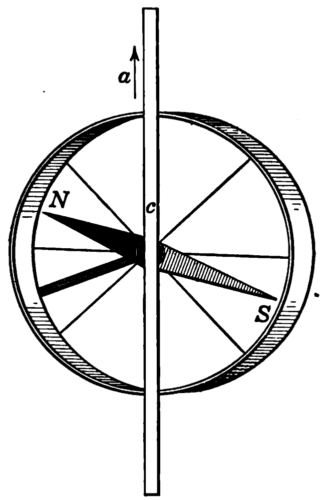


Fig. 33.—Showing the Effect Produced when Two Magnetic Fields are Brought Together.

by the current in the wire circulate in concentric paths at right angles to the wire. Suppose the wire be so placed with respect to the compass needle that it occupies a position directly above it, and that when no current is flowing through the wire the needle points along the direction of the wire. If, then, current be sent through the wire in the direction of the arrow *a*, the needle will be deflected from its original position until it lies nearly at right angles to the wire, as shown in Fig. 33, with its north pole toward the left. André Marie Ampère, a French physicist, noticed this effect many years ago and formulated it in the following way: Imagine a man swimming along the wire in the direction in which the current is flowing and facing the needle. The north pole will, in all cases, be deflected toward his left hand.

The reason for this action is that the magnetic lines of force of the needle and of the wire, in striving to coincide in direction with each other, exert a pulling force both upon the needle and the wire; but as the wire is fixed and the needle free to move, the latter is pulled into the position shown. As long as the magnetic fields developed by the needle and the current-carrying wire are maintained in this manner, the needle will remain in its deflected position. If, however, either the polarity of the needle or the direction of the current in the wire be reversed, the needle will be deflected in the opposite direction, occupying a position at right angles to that shown in the illustration.

204. What commercial applications has the action referred to in Question 203?

Every electric motor or commercial machine for converting electricity into mechanical energy operates by reason of this action. The wire *c* in Fig. 33 corresponds in every such case to the field, and the magnetic needle to the armature, but instead of a permanent magnet, as the needle in Fig. 33, producing the lines of force, they are produced by electrical conductors through which flow currents that are either fed directly into these conductors, as in the case of direct-current motors, or else are induced in them by the currents in the surrounding wires constituting the field, as in the case of the more common types of alternating-current motors. Continuous rotation of the armature is caused in the former case by reversing the direction of the current through the armature at the proper time, and in the latter case by so arranging the conductors in the field that the lines of force developed by the passage of the alternating current through them produce a continued rotary pull upon the armature.

Electrical measuring instruments are also based upon the principles illustrated in Fig. 33. In some of these the pointer is attached directly to the magnetic needle which is mounted within a coil formed by the wire carrying the current. The deflection of the needle being proportional to the strength of

the current through the wire, the pointer attached to the needle can be made to register on a graduated scale the exact quantity being measured. In other types of measuring instruments the magnetic needle in Fig. 33 is replaced by a coil of fine wire through which the current to be measured, or a certain portion of it, is passed. This coil is mounted between the poles of a permanent horseshoe magnet, so that upon the passage of a current through the coil it will turn to enable the lines of force developed thereby to coincide in direction with those of the permanent magnet. A pointer attached to the coil projects over a scale so graduated that the deflection of the pointer as measured upon it gives the exact value of the current passing through the coil.

THE DEVELOPMENT OF ALTERNATING CURRENT IN A DYNAMO

205. Describe in detail how an alternating current of electricity is obtained from a dynamo.

For the present a dynamo or electric generator may be considered as being composed of two parts—the field magnet and the armature, the former to provide magnetic lines of force and the latter to provide conductors suitably shaped for cutting these lines of force. In its simplest form the magnet is of the permanent two-pole type, and the armature a single coil of wire capable of revolving between the poles of the magnet.

Suppose in Fig. 34 that *N* and *S* represent the respective north and south poles of the magnet. Also, that in the field of the magnet *N S*, that is, in the air space between the poles, a loop of wire *a* be placed and the one end of the wire be soldered to a metallic ring *c* and the other end to a metallic ring *e*, each ring being insulated from the other and capable of revolving with the loop *a;* then when *a* is turned either by hand or by mechanical means the cutting of the lines of force by the wire will, through electromagnetic induction, develop an electromotive force or difference of potential between the

ends of the wire and consequently between the metallic rings *c* and *e* connected to them.

If upon each of the collector rings *c* and *e* there is pressed a metallic strip called a brush, and the two brushes *r* and *v* be joined to separate wires *t* and *d*, then between these wires there will also be a difference of potential for the reasons

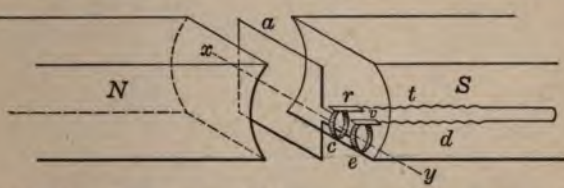


Fig. 34.—Simplest Form of Field Magnet and Armature in a Dynamo.

previously stated. This difference of potential will, if the wires *t* and *d* be connected either directly or by means of a third conductor, force a current of electricity through the closed circuit thus formed, proportional in value to the difference of potential existing at the time.

206. How can the variations of the difference of potential and current obtained in the case of Fig. 34 be best represented?

The difference of potential and the current developed in a single loop will vary in value according to the position of this loop with respect to the poles *N* and *S*. The change of value, however, will be gradual if the loop be revolved about its axis *x y*, and the variations can best be represented for either difference of potential or current by a curve such as *h o m l*, Fig. 35.

In this illustration the distances along the line *h l* represent the angles which the plane of the loop *a*, Fig. 34, forms during its revolution about *x y* as an axis, with its position shown in Fig. 34, and the vertical distances from *h l* to any part of the curve represent the values of the electromotive force or current in the loop at any given position. Inasmuch as the values of the electromotive force, and therefore of the current, in

this case are proportional to the rate at which the loop during its travel cuts the lines of force in the field, the minimum values of these will occur when the sides of the loop are moving nearly parallel to the lines of force, as in the present position of the loop, and the maximum values will occur when the sides of the loop are moving directly across the lines of

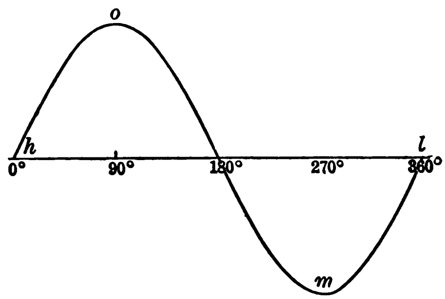


Fig. 35.—Curve showing Variation in Electromotive Force or Current during One Complete Revolution of the Armature.

force, as would be the case when the loop is 90 degrees around from its present position.

Commencing, therefore, at 0 degrees on the line *h l*, Fig. 35, that is, with the loop *a*, Fig. 34, in the position shown, there will be no electromotive force developed. As the loop revolves, however, it cuts the lines of force at an increasing rate and the electromotive force increases proportionally, as shown by the curve, until the loop is one-quarter of the way around, or in its 90-degree position, where the cutting is a maximum. As the loop passes this point in its travel, the rate of cutting decreases for the next 90 degrees, and the curve in consequence takes a downward course, so that when the loop is one-half of the way around or at the 180-degree position, the electromotive force will again be zero. At this point, however, the magnetic conditions to which the revolving loop is subjected are reversed, causing thereby a change in the direction of the electromotive force; if, therefore, the circuit including the loop be closed, a current will flow through this circuit

in the reverse direction to that in which it formerly flowed. The curve, to represent this change, crosses the zero line *h l*, and as the rate of cutting gradually increases in the reversed direction during the next 90 degrees, the distances between *h l* and the curve likewise increase below the zero line, until finally the maximum values are reached at *m*, with the loop three-quarters of the way around. The rate of cutting gradually diminishes during the last quarter of the revolution, and the curve approaches the zero line preparatory to indicating a reversal of electromotive force or current at *l* for the next revolution of the coil.

207. Define the terms "cycle" and "frequency," with reference to Fig. 35.

It is evident, now, that the curve *h o m l*, Fig. 35, represents the instantaneous values of electromotive force or current for each complete revolution of the loop *a*, Fig. 34; that is, it represents their values in the loop at different points in its travel through 360 degrees. This curve is, therefore, said to represent one complete "cycle" of alternating current, and this term is commonly used to express the "frequency" of an alternating current. Thus, if there be one pair of poles, as at *N* and *S* in Fig. 34, and the loop *a* makes one complete revolution per second, then the frequency of such a machine would be, as has just been shown, one cycle per second. The frequency is directly proportional to the number of pairs of poles and the speed of rotation, so that by doubling the number of poles or by doubling the speed of the loop, the frequency will be doubled.

208. How closely do the conditions in Fig. 34 and Fig. 35 represent alternating-current practice?

The line *h o m l* shown in Fig. 35 represents the ideal shape of an alternating electromotive force or current curve. The exact form of an alternating electromotive force curve in any given alternating-current generator or alternator depends upon the design and construction of the machine, and the

exact form of an alternating-current curve depends upon the conditions of the circuit to which the current is supplied.

For the sake of simplicity the most elementary type of dynamo has been chosen to illustrate the preceding principles. Such a machine could develop at best but a very low electromotive force, it would have little output and the frequency would be very small. In the common types of alternators used in practice, therefore, where the electromotive forces range from 1,000 to 13,000 volts, the outputs from 30 to 5,000 kilowatts, and the frequencies from 25 to 140 cycles per second, the higher electromotive forces are attained by increasing the number of turns of wire in the revolving loop, by increasing its speed of rotation and by strengthening the magnetic field; the greater outputs are attained by increasing the number of pairs of poles and the number of loops, the latter of which are composed of larger wire and are connected in multiple with the collector rings; the higher frequencies are attained by raising the speed of the revolving loop or loops, and by increasing the number of pairs of poles.

209. What difference is there between single-phase, two-phase and three-phase alternators?

The simple electric generator presented in Fig. 34 is capable of delivering but a single alternating current and is therefore called a single-phase alternator. By the addition of another loop 90 degrees around from the loop *a* and another set of collector rings electrically connected thereto, two alternating currents may simultaneously be taken from the machine when in operation, on four wires which make contact with the four collector rings through four brushes. Each of the two currents may be represented by a curve similar to that in Fig. 35, but the maximum values of the one would occur 90 degrees in advance of those of the other. A machine thus constructed is termed a two-phase alternator.

If there be three loops spaced 60 degrees apart, and these loops be connected together so that there are three leads from

the three loops with one loop between any two of the leads, and the leads be electrically connected to three collector rings well insulated from each other, then three alternating currents may simultaneously be taken from the machine when in operation, on three wires which make contact with the three collector rings through three brushes. As in the previous case, each of the three currents may be represented by a curve similar to that in Fig. 35, but there will be a displacement of 60 degrees between their respective maximum values. A machine thus designed is called a three-phase alternator. In all modern three-phase alternators, however, the leads from one of the loops are reversed in making the connections so as to cause a displacement of 120 degrees, instead of 60 degrees, between the currents, and thus equalize the strengths of the currents in the three wires. Alternating-current generators of the two-phase and three-phase types are often called polyphase alternators, and the currents developed therein are termed polyphase currents.

DIRECT-CURRENT GENERATORS

PRINCIPLES GOVERNING THEIR ACTION

210. Describe the action of the commutator on a direct-current generator.

In every direct-current generator the electromotive force and current induced in the loop, or loops, revolving in the magnetic field, are alternating, and it is only by virtue of a mechanical device called a commutator that the alternating current is changed into direct current before it leaves the machine. It is exceedingly important that the principle upon which the commutator operates be thoroughly understood,

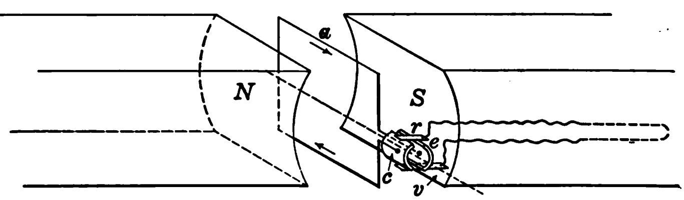


Fig. 36.—Elementary Form of Direct-Current Generator.

and for the purpose of explaining its action reference will be made to Fig. 36.

In Fig. 36 is presented in part a reproduction of Fig. 34; it will be noticed, however, that the brushes *r* and *v*, instead of making contact with two separate collector rings, as in the previous case, now press upon the opposite sides of a cylinder. The cylinder is the commutator, and it consists in this case of two circular copper bars or strips *c* and *e*, which are thoroughly insulated from each other, but electrically connected with the ends of the loop *a*. Twice during each complete revolution of the loop *a* it will be in a vertical position, and as has been previously shown current developed in *a*

changes its direction of flow at these positions. If, therefore, just previous to the loop *a* reaching its vertical position, the direction of the current through it be represented by the arrows, then when the loop, continuing on its course, passes its vertical position, the current developed will flow in the opposite direction to that indicated by the arrows. It will be noticed, however, that each of the brushes at the vertical positions of the loop changes contact from one of the commutator bars to the other, so that, although the direction of the current in the loop is reversed at these positions, its flow through the brushes and through the outside connecting circuit is maintained in one direction; there is, therefore, supplied to the outside circuit a direct current.

211. **Show by means of curves the effect produced by the commutator.**

The effect of commutating the current is clearly shown in Fig. 37, where the full-line curve *a c e s* represents the varia-

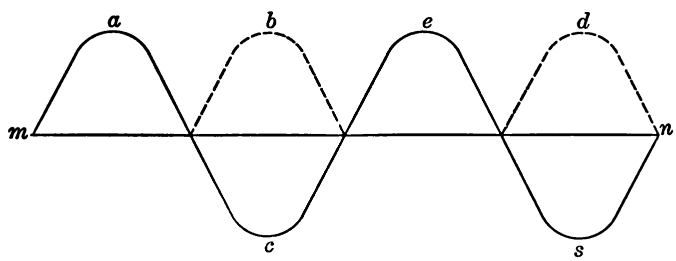


Fig. 37.—Current Curves Showing Action of Commutator.

tions of the alternating current in the loop *a*, Fig. 36, during two complete revolutions. As has already been shown, the brushes change contact with the commutator bars at the instant the current induced in the loop is reversing its direction; that is, at the instant the full-line curve in Fig. 37 crosses the zero line *m n*. The effect of the action in reversing a reversed current is the same as that of using two negatives, namely, a positive result, and this is indicated in Fig. 37 by the broken-line curves *b* and *d*, which are simply the portions

c and *s* reversed. The curve *a b e d,* considered as a whole, consequently lies entirely above the zero line *m n,* and every point on it has a positive value; this curve, therefore, represents a direct current.

212. How is the direct current developed in a generator made to maintain a practically constant value?

It is evident from the shape of the curve *a b e d,* Fig. 37, that the direct current thus represented is not uniform or constant; that is to say, it varies in strength, and for commercial purposes of any nature this feature would be exceedingly objectionable. The remedy consists in providing a greater number of loops in the revolving part of the generator, and having the terminals of each loop connected to two commutator bars in the same manner as has been shown in Fig. 36. Each loop, as well as its respective commutator bars, must be well insulated from the others.

The commutator bars are best mounted side by side with insulation between them, so as to form a cylinder upon which press the brushes. The width of each of the bars is the same and is governed by the diameter allowed for the commutator and by the number of loops, each loop requiring two commutator bars. The lengths of the bars are also equal, and this dimension is governed by the number of amperes generated and the width of each bar.

213. Show by means of curves the effect produced by increasing the number of loops.

The effect produced when a second loop of wire with its respective commutator bars is mounted at right angles to the loop *a* and commutator bars *c* and *e,* Fig. 36, and both are rotated between the poles *N* and *S,* will first be considered. Since each loop and its corresponding commutator bars are insulated from the others, they are perfectly independent of each other, and as each loop is subjected to the same conditions there will be developed in each of them, during any two complete revolutions, a current whose variations are the same as those shown in the curve *a c e s,* Fig. 37. Owing to the

two loops being mounted at right angles to each other, however, the curve depicting the conditions existing in one loop will not, although identical in shape, coincide with the other, but be displaced 90 degrees, as shown in Fig. 38. In this illustration the curve *a c e s* represents the current developed in the loop *a*, Fig. 36, while the curve *t v h o* represents the current developed in the new loop introduced. There being a displacement, or difference of phase, as it is called, of 90 degrees between the two currents, the maximum values of the one occur at the same instant as the minimum values of the other, and *vice versa*, so that these two curves in Fig. 38 are

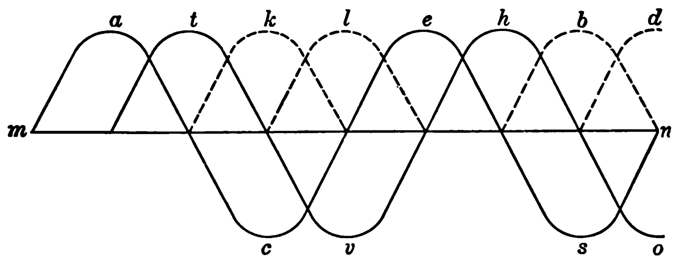


Fig. 38.—Illustrating the Effect produced in Electromotive Force or Current by increasing the Number of Loops and Commutator Bars in the Armature.

a representation of the two-phase current previously defined in Answer 209.

It has already been shown how, by the action of the commutator, that portion of the curve *a c e s* lying below the zero line *m n* is rectified and caused to occupy the position directly above, as shown by the dotted lines *k* and *b*, Fig. 38. By the same process that portion of the curve *t v h o*, lying below the zero line *m n*, is also rectified and caused to occupy a similar position above, as indicated by dotted lines *l* and *d* in Fig. 38. The variations of the current in the outside connecting circuit are those represented by the curve formed by the summits *a t k l e h b d*, and it is evident that the direct current thus represented varies less, or, in other words, is more steady or

constant than that represented by the curve *a b e d* in Fig. 37, where but a single loop was employed.

In like manner the addition of other loops, with their respective commutator bars, will each tend to increase the number of summits forming the curve, until the latter becomes a straight line at the top and represents, in consequence, a direct current of constant value. This being the result sought, commercial direct-current generators are built with many loops and a corresponding large number of bars in the commutator.

214. How closely do the conditions that have here been used to illustrate the principles of direct-current generators represent direct-current practice?

For presenting the principles of direct-current generators, the simplest form of this type of machine was taken for the same reason that the most elementary type of alternator was chosen for illustrating the principles of alternating-current generators, namely, to present the matter in as plain a manner as possible. As in the previous case, a direct-current generator of the simple construction here shown would be extremely inadequate to be used commercially, for in direct-current practice the electromotive forces usually range from 110 volts to 750 volts, and the outputs between 1.5 kilowatts and 300 kilowatts. Owing to the similarity of electric generators, the same factors that determine the electromotive force developed in an alternating-current generator also determine the electromotive force developed in a direct-current generator, so that if in the latter machine the number of turns of wire in each revolving loop be increased, or if the speed of rotation be raised, or if the magnetic field be further strengthened, the number of volts developed will be increased in proportion.

For the same reason, the factors that determine the amperes of current developed in an alternating-current generator are also those that determine the amperes of current developed in a direct-current generator, so that by increasing

the number of pairs of poles, by employing more revolving loops of wire, and by reducing the resistance of the loops by forming them of larger wire and connecting them in multiple with the commutator bars, the output of a direct-current generator may be increased.

Owing to difficulties encountered in securing proper insulation at the commutator, the limiting maximum value of direct-current electromotive force is low, as compared with that of alternating electromotive force; and for a similar reason the limiting output of a direct-current generator is far below that of an alternating-current generator. These statements will be substantiated by a comparison of the corresponding figures given in Answers 208 and 214, representing these quantities.

215. May a dynamo be properly regarded as a source of energy?

No; a dynamo does not create the energy which is taken from it in the form of current. It is simply a machine by means of which mechanical energy is transformed into electrical energy. The mechanical energy is necessary to rotate the loops of wire and the commutator, which together constitute the armature, in the magnetic field, and the power thus expended is always greater than that which it is possible to obtain from the generator in the form of electrical energy. The difference between the two quantities depends upon the losses in the generator, and when these losses are small the efficiency of the machine is high, and *vice versa;* that is, the efficiency, or the ratio of the electrical power generated to the mechanical power applied, is inversely proportional to the losses within the generator.

216. Classify and proportion the losses occurring in the average type of dynamo.

The losses may be classified and proportioned as follows: Friction of bearings and belt, constant at 2 per cent.; friction of the brushes, constant at 0.5 per cent.; friction of the air, constant at 0.5 per cent.; eddy current loss, constant at

1.5 per cent.; hyteresis loss, constant at 1.5 per cent.; resistance loss in armature, variable, but at full load 2 per cent.; resistance loss in field winding, constant at 2 per cent. in shunt-wound generators. The sum of these various losses amounts to 10 per cent., so that the efficiency of such a generator at full load would be 100 per cent. minus 10 per cent., or 90 per cent. This signifies, therefore, that but 90 per cent. of the mechanical power applied to the shaft of the average dynamo is converted into electrical power available for use in the outside connecting circuit.

217. Why is an electromagnet preferable to a permanent magnet for establishing the field of a dynamo?

The function of the field magnet in providing lines of magnetic force to be cut by the armature loops could, in many dynamos, be performed by a permanent magnet were it properly designed; but in commercial generators it is customary to control the voltage developed by varying the number of lines of force in the field. To do this with a permanent magnet is practically impossible, and, furthermore, all permanent magnets, notwithstanding their name, become weakened after a few years' usage, so that, except in certain small machines, such as magneto generators, toy dynamos, etc., the field must necessarily be established by means of electromagnets.

218. Illustrate and describe the general construction of field magnets.

Field magnets may be said to consist of two general parts—the cores and the windings. The cores of field magnets are made of soft iron, usually in the shapes shown in Fig. 39, and are wound around with insulated copper wire, as there indicated in section by the dots. By varying the current passing through this wire, the strength of the field and therefore the voltage developed by the generator are under perfect control.

In order to best distribute the lines of force through the armature, it is necessary that the north and south poles of the field magnet alternate with each other, so each adjacent

pole is wound in the reverse direction to the one preceding it. The separate windings of the poles are then joined in series with each other and the two terminals of this winding, considered as a whole, are connected to a source of current. The current used may be generated in the machine itself, or it may be obtained from an independent generator; in the

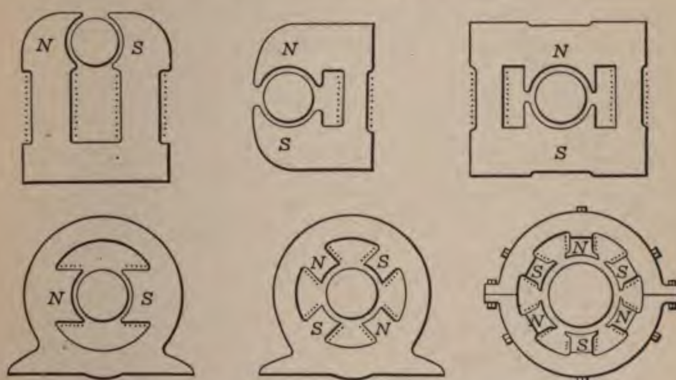


Fig. 39.—Typical Forms of Field Magnets.

former case the field is said to be self-excited, and in the latter case separately excited.

219. In a self-excited generator, how can a current be produced by means of an electromagnet and the electromagnet be excited by means of the current thus produced?

This action is brought about by virtue of residual magnetism, or the power possessed by iron of retaining a portion of the magnetism developed by a current after this current has ceased to pass through the winding of the magnet. The field, therefore, has a few lines of force passing through it, due to residual magnetism, when the armature is first started to rotate. These few lines of force being cut by the armature coils develop in them a low electromotive force, and this being supplied to the field-magnet winding causes a current to pass through it, which in turn develops more lines of force in the field, and in consequence a higher electromotive force.

In this manner the field and the electromotive force are each alternately increased in strength until normal conditions are obtained and the machine is developing a constant voltage.

220. Are all self-excited generators arranged the same? No, self-excited generators may have their field magnets series wound, shunt wound or compound wound, and according to their winding are called series generators, shunt generators or compound generators.

SERIES GENERATORS

221. Illustrate and describe a series generator. In a series generator all the current that is produced by the armature passes through the field-magnet winding, which

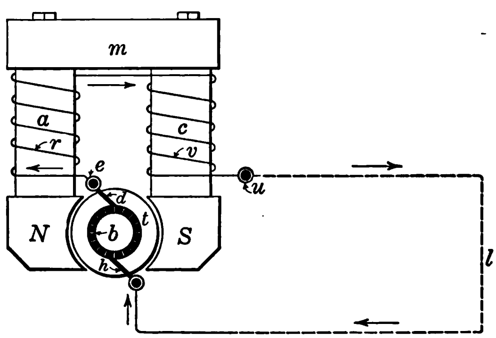


Fig. 40.—Series Generator.

latter must therefore be in series with the outside circuit. For regulating the voltage of a series generator, it is customary to connect an adjustable resistance, called a rheostat (see Fig. 269), across the entire field-winding; by varying the resistance thus introduced, more or less current is shunted from the field coils and the number of lines of force in the field thereby changed.

In Fig. 40 are indicated the principal features of a two-pole machine of the series type. The parts *N* and *S* are of iron and are called the pole pieces, the letters representing

the respective north and south poles of the magnet; *a* and *c* are called the limbs or cores of the magnet, and it is upon these that the field coils *r* and *v* are wound in reversed directions, as indicated. Joining the cores *a* and *c* is the iron yoke *m*, and between the pole pieces revolves the armature *t*. By means of the brushes *d* and *h*, which press upon the commutator *b*, the current developed in the armature is led around the field coils, as indicated by the arrows, and after passing through the outside connecting circuit *l* returns to the armature. If a rheostat were used for controlling the voltage, as previously mentioned, it would be connected in circuit at *e* and *u*, so that the current would divide itself between the field winding and the rheostat.

222. How is the actual performance of a generator best represented?

The performance of a generator under an increase of load or current depends primarily upon which of the three previously mentioned classes of self-excited machines it belongs to, and the general results that may be expected in each of these cases are best represented by means of a characteristic curve.

223. Explain how a characteristic curve of a generator is obtained?

A characteristic curve, irrespective of the type of generator from which it is derived, is obtained by running the generator at its normal speed, which is maintained constant, and by varying the resistance in the outside connecting circuit, so as to secure different values of the current in the circuit, together with the corresponding electromotive forces across the terminals of the machine.

The values of electromotive force for currents ranging from zero to a maximum are plotted on co-ordinate paper and determine by their positions the direction of a curve which, although technically termed a characteristic curve, might with equal propriety be referred to in the language of the

steam engineer as the "indicator diagram" of the generator.

224. **Illustrate and explain the usual form of characteristic curve obtained from a series generator.**

The usual form of characteristic curve obtained from a series generator is shown in Fig. 41, the electromotive forces in volts forming the vertical scale of ordinates and the currents in amperes constituting the horizontal scale of abscissæ. Commencing with no load or amperes—that is, with the outside connecting circuit open—the reading on the curve from the vertical scale is seen to be about 3 volts. At first thought one would suppose that since the outside circuit is open there would be no current through the field coils, and, consequently, no voltage at this point, but if the reader bears in mind what has previously been mentioned about residual magnetism he can easily account for the 3 volts.

A further investigation of Fig. 41 shows the first part of the curve to be nearly a straight line representing a proportional increase of voltage with increase of current, but after a certain current is reached (about 18 amperes for the series generator here depicted), the curve flattens and takes a downward direction. This turning point *A* occurs in the characteristic curves of all series generators and denotes the stage at which the iron field cores become so saturated with lines of force that they will not readily allow more to pass through them; it is technically known as the point of saturation, and the current corresponding is called the critical current of the generator.

225. **What significance is attached to the point of saturation and critical current of a series generator?**

The point of saturation in any given series machine is governed by the amount of iron in the magnetic circuit; its position in the curve, therefore, varies according to the design of the generator, as does also the critical current. The value of the latter is important, inasmuch as the valuable features of a series generator assert themselves only when the machine

is supplying a greater number of amperes than that of the critical current, for if the series generator be worked along that part of the curve to the right of the point of saturation it becomes nearly self-regulating as regards current, because as the current increases the voltage drops. Thus, if the re-

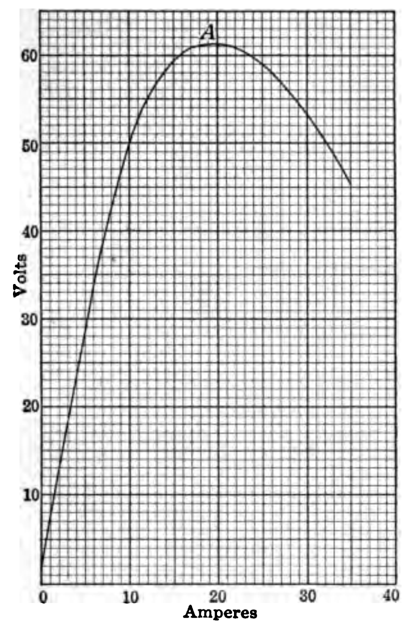


Fig. 41.—Characteristic Curve of Series Generator.

sistance of a circuit supplied by a series generator be increased, the current will be diminished, but if the machine be working at the proper part of the curve it is seen that under these conditions the voltage will rise and so force more current through the circuit. Therefore, where a constant current is required, as in certain types of arc lamps, etc., a series generator meets the conditions very satisfactorily, if operated beyond its point of saturation.

SHUNT GENERATORS

226. Illustrate and describe a shunt generator.

In a shunt generator the field winding is connected in multiple with the outside connecting circuit, so that when the outside circuit is open the field magnet coils receive the entire current supplied by the armature, but when it is closed the current through the field circuit depends upon the resistance of the field circuit as compared with that of the outside connecting circuit. By connecting a rheostat or adjustable

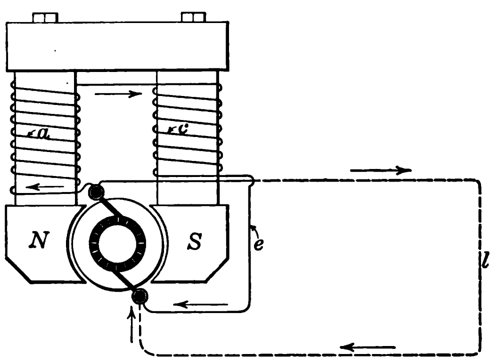


Fig. 42.—Shunt Generator.

resistance in series with the field winding, a greater or less amount of current may be permitted to pass through the magnet coils at any one time and the voltage of the machine is thereby controlled.

In Fig. 42 are indicated the principal features of a simple machine of this type. The shunt field coils *a* and *c* are of much smaller wire than that composing the field coils of the series generator, but there are many more turns. The field winding has therefore a high resistance and allows the passage of but 2 or 3 per cent. of the total current generated. As in the diagram of the series generator, *l* denotes the outside connecting circuit, and the direction of the current is represented by the arrows.

227. At what point is the field rheostat for controlling the voltage usually introduced?

The field rheostat is generally connected in circuit at *e*, Fig. 42, the circuit being opened at this point and the two wires inserted in the binding posts of the rheostat.

228. Illustrate and explain the usual form of characteristic curve obtained from a shunt generator.

The usual form of characteristic curve obtained from a shunt generator is shown in Fig. 43. Unlike the series gen-

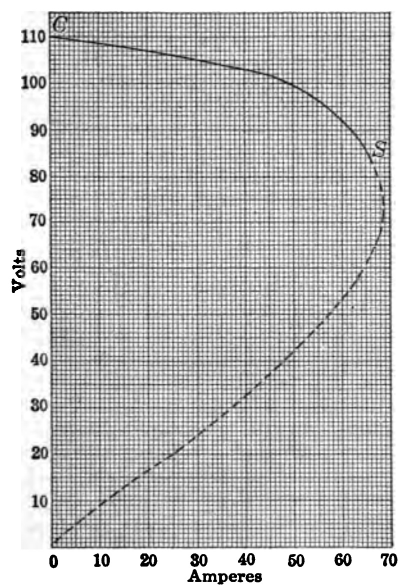


Fig. 43.—Characteristic Curve of Shunt Generator.

erator, this machine gives its maximum voltage when the outside connecting circuit is open. Starting under these conditions, therefore, the curve in Fig. 43 commences at *C*, showing 110 volts with 0 amperes. Increasing the current in the outside circuit causes the voltage to drop, first slightly and then rapidly, until the point *S* is reached, when any further lowering of resistance in the outside connecting circuit causes

a rapid decline in the voltage and afterward of the current, as shown by the dotted portion of the curve, until both voltage and current become approximately zero.

Usually, a very slight current results, even when the terminals of the machine are short-circuited, due to residual magnetism in the pole pieces, so that the dotted portion of the curve generally terminates not exactly at zero, but at a point some distance along the current line. The working portion of the curve is from C to S, at which time the machine is supplying a fairly constant voltage. The shunt generator is, therefore, best adapted for constant potential work, such as lighting and power service.

COMPOUND GENERATORS

229. Explain the action of the field windings on a compound-wound generator.

The characteristic curves show that in a generator with a series-field winding an increase of current in the connecting circuit, such as would result from lowering the resistance of the circuit, causes the machine to develop a higher voltage, or produce what is known as a rising characteristic; whereas in a generator with a shunt-field winding conditions producing an increase of current in the outside connecting circuit tend to reduce the voltage or give a falling characteristic. In a compound-wound generator there are both a series-field winding and a shunt-field winding acting simultaneously, and the ampere-turns in the one are so proportioned to those in the other that the load or current conditions in the outside connecting circuit which would cause the one winding to produce a low pressure will at the same time cause the other winding to produce a high pressure, and *vice versa.* The combined result of the two field windings is, therefore, to supply a practically constant pressure at all loads.

230. Into what two classes may the field windings of compound-wound generators be divided?

Into short-shunt compound windings and long-shunt compound windings.

231. Illustrate and describe a compound generator with a short-shunt winding.

A compound generator with a short-shunt winding is shown in Fig. 44. The series field winding *a c*, as in the series generator previously presented, is composed of a few turns of heavy wire in series with the outside connecting circuit *l*. The fine-wire shunt winding *u v* is composed of many more

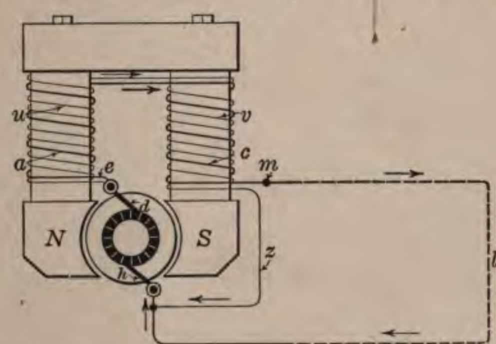


Fig. 44.—Compound Generator with Short-Shunt Field.

turns than the series winding, and is joined directly to the two brushes *d* and *h*. The adjustable rheostats for pressure regulation would, as in the corresponding separate cases already considered, be connected for the series field winding between the points *e* and *m*, and for the shunt field winding at some convenient point, as at *z*.

232. What sort of rheostats or resistances are used for the series and shunt fields of a compound generator?

It is common practice in compound-wound machines to use flat strips of German silver across the series field, the number and cross-section of these strips being such that their temperature under normal conditions will not exceed 30 degrees Centigrade above that of the atmosphere, and their length such as to enable the series field to produce the desired voltages at the different percentages of full load. As both these conditions in any given generator may usually be satisfied

by a constant resistance, the strips are made up to be used as a whole without necessitating adjustments.

The resistance used in the shunt field, however, must be of the usual hand adjustable type shown in Fig. 269 to maintain a constant pressure under variations in the speed of the armature, or in the load on the outside connecting circuit.

233. Illustrate and describe a compound generator with a long-shunt winding.

A compound generator with a long-shunt field winding is shown in Fig. 45. It differs from the short-shunt field winding

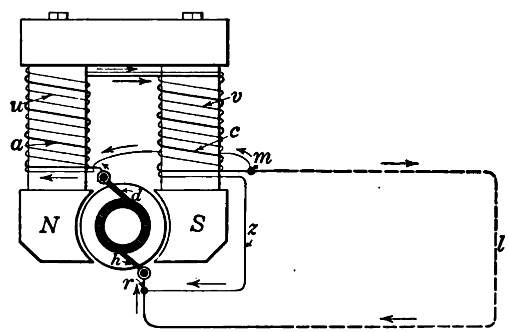


Fig. 45.—Compound Generator with Long-Shunt Field.

in that the shunt winding *u v* here includes the series field winding *a c,* being connected to the terminals *r* and *m* of the machine, instead of to the terminals or brushes *d* and *h.* In this arrangement all the current that passes through the shunt field winding must necessarily pass through the series field winding.

234. For what kind of work is the short-shunt compound field winding preferable to the long-shunt compound field winding?

Where the load in the armature circuit varies considerably from time to time, rendering it necessary to frequently change the strength of the field in order to maintain the proper voltage, the short-shunt method is the better, because a varia-

tion of the adjustable resistance z, Fig. 44, in the shunt field winding then exerts a more pronounced effect on the strength of the field than it would were the series field winding and its regulating resistance also in circuit.

235. For what kind of work is the long-shunt compound field winding preferable to the short-shunt compound field winding?

Where the generator is carrying a practically constant load requiring little if any variation of pressure, then the long-shunt method is preferable, because in this arrangement the current through the shunt coils is steadied by its passage through the series coils and their regulating resistance, rendering it still more capable of maintaining a uniform pressure.

236. Illustrate and explain the usual form of characteristic curve obtained from a compound generator.

The characteristic curve obtained from a compound generator is practically the same whether a short-shunt field winding or a long-shunt field winding is employed.

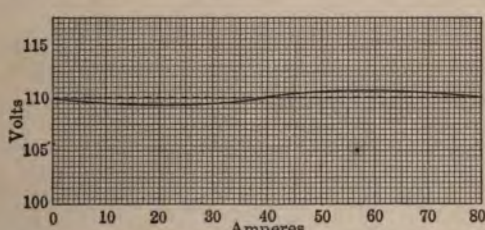


Fig. 46.—Characteristic Curve of Compound Generator.

In Fig. 46 a characteristic curve of a compound-wound generator is shown. The machine from which this curve was obtained had its series and shunt field coils so proportioned as to produce practically a constant pressure of 110 volts at all loads—that is, between no load or 0 ampere and full load or 80 amperes.

The ideal characteristic curve representing absolutely constant voltage at and between these points would, of course,

be a straight line extending from the 110-volt point parallel to the base line, but the actual curve departs from the ideal conditions represented by the dotted line, but slightly, and represents sufficiently constant pressure for all commercial purposes.

237. **Illustrate and explain the usual form of characteristic curve obtained from an over-compounded generator.**

The characteristic curve shown in Fig. 47 was obtained from an over-compounded generator—that is, from a compound-wound machine designed to supply a higher pressure at full load than at no load. Thus, it is seen from this curve

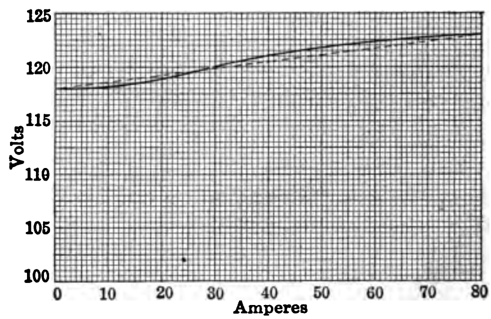


Fig. 47.—Characteristic Curve of Over-Compounded Generator.

that at no load the pressure across the terminals of the machine was 118 volts, while at full load or 80 amperes the pressure was 123 volts. The amount of over-compounding in this case was, therefore, 5 volts, but even 10 volts is not an uncommon figure.

As in the previous case, the actual curve departs from the ideal but slightly, the latter for this machine being a straight line, as shown dotted, joining the extremities of the curve.

From what has already been stated, it is evident that over-compounding is brought about by increasing the number of turns in the series winding relatively to those in the shunt winding; the practice of thus compensating for the drop in pressure due to line resistance is a common one in long distance direct-current transmission.

SPARKING

238. Which is the most common of all troubles associated with direct-current generators?

Sparking at the commutator. All machines provided with commutators suffer more or less in this respect, and as the causes that produce sparking vary considerably in the various types of direct-current generators it is not always a simple matter to locate and remedy them.

239. Why is sparking at the commutator an objectionable feature?

Because it tends to injure the brushes and the commutator by burning and charring them; it also produces abnormally high temperature and impairs the regulation of the machine.

240. Do generators spark constantly?

Most direct-current generators are sufficiently well designed to run without sparking at their rated full load. At 50 per cent. overload, however, they usually show some slight sparking, and at double their rated full load a considerable amount of sparking.

241. How can sparking due to excessive loads be recognized as such?

Either excessive voltage or abnormally high current can at once be detected on the measuring instruments—that is, on the voltmeter or ammeter, and the remedy for sparking thus caused consists, of course, in reducing either the voltage or current to its normal value.

242. Is not sparking often caused by a rough or uneven commutator?

A rough or uneven commutator invariably causes sparking; and this defect is of a sufficiently serious nature to merit immediate attention.

243. How may sparking due to a rough commutator be detected and remedied?

A rough commutator may be detected by a close inspection of its surface, while stationary. Rubbing the hand over it

will quickly afford the required information, and if it be found rough, the use of sandpaper is recommended. This should be applied to the commutator by the aid of a block of wood hollowed out to conform to the curvature of the commutator, and in which the sandpaper is placed. The commutator should be rotated at a moderate speed while the sandpaper is thus pressed against it. If the surface is very rough a coarse grade of sandpaper should first be used, followed by a finer grade in finishing; otherwise, fine sandpaper should be used throughout the smoothing process. Emery cloth should not be used for smoothing the commutator under any circumstances.

Sometimes sparking is due to the mica insulation between the copper bars of the commutator not wearing at the same rate as the copper. The insulation then projects above the bars, so that the brushes cannot remain in close contact with the commutator, and sparking will invariably ensue. In such a case the projecting mica must be cut down to a level with the bars.

244. What is the remedy for an uneven commutator?

An uneven commutator is caused by some of the bars wearing more than others, owing to a difference in the hardness of the copper of which they are made. If this trouble is very noticeable, the commutator must be turned down.

245. How may roughness of the commutator be prevented?

Roughness of the commutator may be prevented to a considerable extent by providing the armature with sufficient end-play so that it has a slight motion, say a sixteenth or an eighth of an inch back and forth in the bearings; this motion prevents the brushes bearing on the same part of the commutator continuously. Usually, if the shoulders on the armature shaft be properly spaced to allow for end-play, the backward and forward motion will be automatically imparted to the armature, although there are on the market mechanical oscillators intended for this purpose.

Machine oil and vaseline are often used on rough commutators to ameliorate conditions. If either of these be applied occasionally in very small quantities the results are beneficial. The best way to apply these lubricants is by means of a cloth on which the oil or vaseline is placed, the cloth being moved slowly across the surface of the commutator while it is in motion. If too much oil or vaseline is used on the commutator, both brushes and commutator are liable to become dirty because the conditions are favorable for the accumulation of dust, and this results in poor contact between them. A commutator in perfect condition usually takes on a dull glaze of a bronze or brownish color, rather than a bright or scraped appearance.

246. What effect does the condition of the brushes have upon sparking?

If the brush faces make poor contact, owing to their being improperly trimmed or set with respect to the commutator, or on account of there being dirt on their surfaces of contact, sparking is liable to ensue. Hard spots in carbon brushes also cause sparking, by not wearing so as to allow all points on the faces of the brushes to touch the commutator. An insufficient pressure of the brushes upon the commutator, or a brush of very high resistance, are other causes tending to produce sparking.

247. State how brushes may be properly trimmed.

The trimming of a brush to make it conform to the surface of the commutator is, in the case of copper brushes, best accomplished by means of a brush jig. This consists of a frame in which the brush is securely held while its end projects through a slanting surface. The end of the brush, when filed down even with this surface, has the proper shape, and is therefore correctly trimmed.

With carbon brushes the trimming process consists, first, in giving their contact surfaces a rough shaping by fastening a band of coarse sandpaper around the commutator and slowly revolving the armature while the brushes

are pressing upon the sandpaper. Then the coarse sandpaper is removed, and a short strip of a finer grade of sandpaper is pulled back and forth by hand between the commutator and each brush separately, as shown in Fig. 48.

248. How should the brushes be given their proper position around the commutator?

The proper position of the brushes around the commutator can best be found with reference to their sparking condition.

Fig. 48.—Method of Sandpapering Carbon Brushes.

If the brushes be shifted too far in one direction there will be sparking, and if they be shifted too far in the opposite direction there will also be sparking; their proper location, therefore, lies midway between these two positions, and by turning the rocker arm to which the brushes are mounted, so as to bring them into this intermediate position, they all may properly be placed simultaneously.

If, in a two-pole machine, the brushes are not exactly opposite, or if, in a four-pole machine, they are not 90 degrees apart, they should be set so. A convenient way of testing for the proper distance apart consists in counting the com-

mutator bars between them, although the peripheral distances may be measured by means of a string or tape. It is also necessary that the brushes on each stud be in line with each other. If they are not in line, the set of brushes may cover too much of the commutator to permit sparkless operation.

249. Which is the best way of cleaning the brushes?
By means of an oily rag or by the use of benzine.

250. Is there any remedy for a carbon brush in which there are hard spots, or for a carbon brush of abnormally high resistance?
No; brushes having either of these defects should be replaced by new ones. A brush with hard spots may be detected from the appearance of its contact surface, which will show that it touches the commutator at but one or two points. A brush of high resistance can be detected by its high temperature while in service, or by measurements.

251. How much pressure should a brush exert upon the commutator?
The pressure should be sufficient to insure a good electrical contact and yet not enough to develop an appreciable amount of heat by friction. A pressure of about $1\frac{1}{2}$ pounds per square inch of contact surface has been found to be sufficient for carbon brushes.

252. What is the best way to determine the pressure of a brush upon the commutator?
By means of a spring balance, hooked to the brush and held in line with it but perpendicular to the surface of the commutator, as shown in Fig. 49. The reading on the balance *d*, when exerting a sufficient pull to just raise the brush *e* from the surface *a* of the commutator, is the total pressure; dividing this by the brush contact area will give the pressure per square inch. By adjusting the tension screw *s* of the brush holder *c*, the pressure per square inch may be varied until the proper amount has been obtained.

253. State how a short-circuited or a reversed armature coil which produces sparking may be detected and remedied.

A generator with a short-circuited or a reversed coil in the armature cannot easily be brought up to its rated voltage while delivering a normal current. This difficulty, together

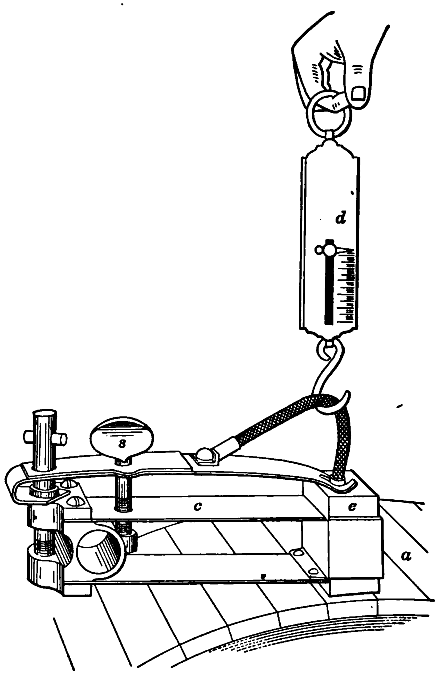


Fig. 49.—Measuring Pressure of Brush on Commutator.

with the fact that the defective coil if short-circuited will become considerably warmer than the others, and the increased amount of power necessary to run the generator even without load, furnish a means of detecting this trouble. A run under full load for only a few minutes is sufficient to heat up a short-circuited coil so that it is noticeable to the sense of feeling. If run thus for a considerable time, the excessive current developed in a short-circuited coil will be very liable to burn it out entirely. The generator must, therefore, be

stopped at the first intimation that a short-circuit exists in the armature. If it is impossible to locate the short-circuited coil by the sense of feeling, it can easily be found by sending a normal current through the armature and measuring the drop in voltage or difference of potential across each coil. Unless one or more of the coils are short-circuited, the "drops" should be practically equal.

As a short-circuit in the armature is usually due to solder or some conducting foreign matter, such as carbon or copper dust from the brushes getting between the commutator bars or between their connections with the armature coils, the remedy is usually of a simple nature, consisting merely in removing the offending particles. In some cases, however, the insulation between the commutator bars becomes carbonized by excessive and continued heat, thus causing a leakage of current which gradually increases until a heavy load is being uselessly carried by the generator. As a rule, the insulation is carbonized at the surface only, and the trouble can be removed by turning off the commutator in a lathe.

In cases where the short-circuit is in the coil itself, the remedy consists in replacing the coil with one thoroughly insulated. This is a comparatively simple matter if the armature is wound with formed coils, but if it is not thus constructed, the entire armature may have to be removed. If the trouble is caused by a reversed coil, transposing its connections with the commutator bars or with the leads running thereto will be all that is necessary to correct the trouble.

254. Explain how a grounded armature may produce sparking.

In order that sparking be caused by a grounded armature there must be two grounds or unintentional connections between the armature winding and the iron core, shaft, or spider on which the armature is mounted. If there were but a single ground between these parts, no sparking would result, because there would be no complete path formed for the current, but with two grounds there would be a complete

path for the current and the effect would be the same as that of a short-circuit in the armature; sparking would therefore result, on account of the excessive load carried.

255. How may a grounded armature be detected and remedied?

A test of the insulation resistance of the armature conductors with respect to the iron portion of the machine would be the most direct way of detecting this trouble. A magneto testing set such as described in Answer 506, with one terminal in contact with an armature wire and the other terminal in contact with the frame of the machine, would ring upon the turning of its crank if the armature was grounded at one or more places. The drop of potential method described in Answer 253 for detecting a short-circuited armature coil will show if the armature is grounded in two places. The remedy for a grounded armature consists in replacing the defective coil or coils with others having perfect insulation.

256. What indications point to sparking being caused by a broken circuit in the armature?

If one of the commutator bars is badly burnt it is an indication that there is an open circuit near it. The sparking in this case will generally be of a violent nature, partaking rather of flashes than sparks. The test for an open circuit in the armature may be made with a magneto testing set, or by means of the drop of potential method previously explained. In many instances of this kind a test is not necessary, as the trouble may be due to one of the armature conductors or leads breaking loose from a commutator bar, in which case the trouble can easily be seen from an examination of the armature.

257. How may an open circuit in the armature be permanently or temporarily remedied?

If the generator can be cut out of service until a permanent remedy is effected, it is advisable in all cases to do so. Then, if the trouble is in the armature coil itself, it may

be rewound; or if in the connection between the armature winding and commutator, it may be remedied by soldering or screwing the loose conductor in place. In emergencies, however, where the defect cannot at once be remedied, and it is impossible to shut down the generator for any length of time, then, in the case of a broken commutator connection, the disconnected bar may temporarily be joined to an adjacent one by soldering or forcing together the copper across the mica insulation at the end of the commutator.

Another makeshift is to stagger the brushes so that in each set one of them projects a little beyond the others, thereby bridging the gap between the disconnected bar and the adjacent ones when this portion of the commutator passes under the brushes. When the break is in the coil itself, temporary remedies of the same nature as those just mentioned may be employed to bridge together the two commutator bars between which the open circuit exists, or the terminals of the armature winding which connect with these bars may be joined together instead.

258. State how sparking caused by a weak magnetic field may be detected and remedied.

With a weak field, the magnetism developed by the armature current becomes relatively strong and shifts the point of minimum sparking from its normal position, and as the brushes remain stationary, sparking results. The weakness of the field may be caused by too small a field current, by a reversed connection of a field coil causing it to oppose the others, or by an improper connection of the series field on a compound-wound generator with respect to the shunt field, causing the series coils to lower the voltage with increase of load instead of raising it.

The improper connection of the individual coils with respect to each other may be detected by holding a compass needle near the poles of the field magnets while the field current is passing through the set of magnet coils undergoing test. In thus passing the compass needle from pole to pole in succes-

sion around the machine, the north and south poles of the needle should be attracted alternately to the pole-pieces. The proper or improper connections of the series coils on a compound-wound generator with respect to the shunt coils may be ascertained by noting if the current passes through both sets in the same direction; this it should do in order to produce the proper results.

The remedy for a weak field caused by too small a field current depends, of course, on its cause. If cutting out resistance in the field rheostat fails to produce the desired result and it be known that the field coils are properly connected, the resistance of the field coils may have to be reduced by unwinding a few layers of wire from each of them or by substituting other coils. A weak field caused by an improper connection of the field coils requires only the reversal of the connecting leads.

259. In what way do vibrations cause sparking, and how may they be alleviated or removed?

Vibrations of the machine resulting from a poorly balanced armature or pulley, a defective belt, or an unstable foundation, cause the brushes to make poor contact with the commutator and produce sparking. While sparking due to vibrations of the machine may be alleviated by giving the brushes a greater pressure on the commutator, the increased friction resulting will develop trouble from another source—heating.

If a poorly balanced armature or pulley is responsible for the vibrations, a change of speed will produce a great change in the vibrations; so much so that at certain speeds the vibrations will almost entirely disappear. Having thus located the trouble, the armature should be removed from the machine and tested upon two knife-edge or A-shaped iron rails placed horizontally and parallel to each other at a sufficient distance apart to support the ends of the armature shaft with the armature body between them. During this test the pulley should be removed from the shaft, and afterward tested in a similar manner separately, if necessary. If the armature

be rolled slowly back and forth upon the iron rails, the heavy side will gravitate to the lowest position. This extra weight should either be counterbalanced by soldering a piece of lead to the light side of the armature core, or removed by drilling or filing away a portion of the metal on the heavy side.

Vibrations caused by a defective belt may be due to its joint pounding against the pulley. As this pounding occurs but once during each revolution it can easily be detected, and it may be remedied by using a belt with a smoother joint, or better still, an endless belt. The foundation of the machine, if unstable, should be made level and firm.

HEATING

260. Can a generator operate without heating?

No, in all dynamo-electric machines heat is developed, but in varying degrees. The conductors are heated by carrying current, the iron cores of the magnets and armature are heated by the variation in magnetic lines of force, and the bearings are heated by friction. The armature core and pole faces are also heated by eddy currents generated in them. Those parts which are not heated directly are often heated indirectly by conduction from those portions of the machine in which heat is developed.

261. What are the allowable temperatures in the various parts of a direct-current generator operating continuously under full load conditions?

The temperature of either the field magnet coils or the armature winding should not exceed 50 degrees Centigrade above the temperature of the surrounding air, as determined by measurements of their respective resistances. The temperature of the commutator or brushes, as measured by a thermometer, should not exceed 55 degrees Centigrade above the temperature of the surrounding air. The temperature of the bearings, as measured by a thermometer, should not exceed 40 degrees Centigrade above the temperature of the surrounding air.

262. Why were these particular temperature limits chosen?

In order that the insulation of the machine may not be impaired, and that the iron in the armature core may not deteriorate by overheating.

263. Is there a convenient method of ascertaining whether or not a machine is developing too high a temperature?

Ordinarily, the condition of a machine with regard to heating can be estimated roughly by touching the accessible parts with the back of the hand. If the hand can comfortably be held on a certain part of the machine for several seconds, the temperature of that part may roughly be said to lie within the limits previously given. The back of the hand is better than the palm for estimating the temperature, because it is more sensitive to heat. Experience will soon enable one to become adept in this manner of testing for abnormal temperatures, but the fact must not be forgotten that the smoothness of the surface touched has considerable to do with the result obtained, as does also the character of the material of which the part undergoing test is composed.

264. Why is it often difficult to locate in a generator the heated part which is the source of the trouble?

Because the heat developed spreads rapidly over the machine, owing to the heat conductivity of the iron portions. If, however, the machine be allowed to cool off thoroughly, then started up for a five-minute run under normal conditions, the heat will not have sufficient time to spread and the defective part may more readily be located if the various parts be tested with the hand as soon as the machine is shut down.

265. Which is the most common cause of abnormal heating in a generator?

An overload due either to actually pushing the machine

beyond its rated output, or to short-circuited armature coils, commutator bars or field coils, is the commonest cause. Usually, in the case of an overload on the machine, there is sparking as well as heating, so that the combination of these symptoms furnishes a clue to the cause of the heating. By following the directions previously given for correcting sparking that is due to overload, or short-circuited coils or bars, the cause of the abnormal heating may also be removed.

266. How may heat developed by the brushes be detected and remedied?

The hand affords the readiest means of judging roughly the temperature of the brushes, but it is better to use a thermometer held against the brushes and protected from the surrounding air by a wad of waste. It may be possible to reduce the heating sufficiently by shortening the distance between the brush-holders and the commutator, thereby diminishing the length of brush through which the current must pass, and consequently lowering the resistance offered by the brush. Other means for lowering the brush resistance and, therefore, the brush temperature, consist in using a greater number of brushes and brush-holders in each stud, reinforcing the brushes with strips of copper or copper gauze, and in improving the connections between the brush-holders and the brushes.

267. Under what conditions will the commutator attain an abnormally high temperature, and what remedies should be applied?

If the commutator be allowed to become very dry, or the pressure of the brushes on the commutator be too great, both brushes and commutator will attain a high temperature. The application of a few drops of oil to the surface of the commutator in the former case, and the adjustment of the brush-holder springs in the latter case, as previously described in connection with sparking, will remedy these defects.

268. Explain how moisture in the field coils or armature coils of a generator tends to raise their temperature, and how it may be detected.

Moisture, being a conductor of electricity, though a poor one, reduces the insulation between the convolutions of the windings and ultimately breaks it down and short-circuits the windings. This trouble may sometimes be detected by the steam heat that arises from the coils when carrying their normal current, by their decreased insulation resistance as determined by measurement, and by the additional power required to run the generator without load.

269. How may moisture in the field coils or armature coils of a generator be removed?

Preferably by passing a moderate current, beginning with about one-fourth the normal current, through the coils, until the heat developed by the current dries out the moisture somewhat, and then increasing the current gradually until the insulation resistances of the coils attain their normal values. Another method, not so easily applied, however, consists in baking the armature or field coils in an oven until the normal insulation resistance is obtained.

270. Can the magnet poles and armature cores be prevented from overheating by eddy currents developed in them?

Yes, to a great extent, by building up the iron composing these parts with laminæ or thin sheets of metal, instead of making them solid. All armature cores and most pole faces are so constructed, otherwise eddy currents would be developed in them which would raise the temperature of the cores and indirectly the temperature of the windings on them. Heating from this cause may be distinguished from that due to a short-circuited armature coil by the fact that eddy currents do not cause sparking, whereas a short-circuit always produces sparking, as previously stated. Moreover, the windings will be uniformly heated, whereas with a short-circuited armature coil the excessive heating will be localized

in one place. The core, furthermore, will be considerably warmer after a run than the coils on it, if eddy currents are causing the trouble. The temperatures for this comparison should be taken with thermometers, as the hand is not sufficiently sensitive to allow for the difference in conductivity of the insulation on the wire and that of the bare metal of the core.

271. State the usual cause responsible for hot bearings on a generator.

Poor lubrication, due to absence of oil or to faulty oiling apparatus, or to a poor grade of oil. Before starting up a machine, and throughout its operation, a close watch should be kept on the oil supply to see that the oil reservoir is well filled, that the oiling rings on the shaft are working properly, and that the oil passages do not leak or become filled with foreign matter so as to prevent oil from passing freely through them. It is advisable to filter the oil, if there is any doubt as to its being clean. If dirt, either present in the oil or deposited from an outside source, works its way into the bearings, it will cause the bearing surfaces to become roughened, and the increased friction between the shaft and bearings will cause heating.

272. Are there any unusual causes that may result in the bearings on a generator becoming unduly heated?

If the bearings are not in line with each other, the armature shaft will bind and will require considerable power to turn it in the bearings. If it be kept in motion the bearings will become very hot. If the machine be equipped with self-alining bearings, however, they will rarely be found to heat from this cause. Again, if a heavy load is being carried by a belted generator, the pull on the belt will cause the armature shaft to press heavily against that side of the pulley bearing toward the engine, and this will cause the pulley bearing to become much warmer than the bearing at the commutator end of the generator. If the temperature thus caused becomes so great that the hand cannot be held comfortably on the

pulley bearing, either the load must be reduced, the pulley replaced by a larger one, or the tension on the belt reduced.

Again, if there is not sufficient end play, either the shoulder or the pulley hub on the armature shaft is liable to press constantly against one of the bearings while the machine is in operation, and thus raise its temperature. Still again, after a machine has been in operation a long while its bearings naturally become worn, and as the wear is generally greatest on one side, the armature is brought nearer to the pole faces on that side of the machine than elsewhere. On account of the shorter air space thus formed in the magnetic circuit between the field poles and the armature, there is a greater magnetic attraction of the armature toward the poles on that side of the machine. The pull thus exerted is similar to that caused by the belt on a heavily-loaded generator, except that it acts on both bearings, and the bearings are liable to become heated on account of the localized friction. This trouble can, however, be remedied by rebabbitting the bearings, thus bringing the armature perfectly central within the pole-face circle and equalizing the magnetic attraction over its surface.

273. **In case the bearings of a generator become very warm while the machine is in operation, what temporary remedy may be applied to prevent shutting down?**

Under the conditions mentioned, the application of ice or cold water is permissible. It is very important, however, that in applying this remedy the water be not allowed to reach the commutator, armature or field-magnet coils, on account of the danger of the water short-circuiting or grounding them. In many extreme cases of heated bearings the course just mentioned is preferable to the other extreme, namely, that of shutting down the machine and keeping the armature stationary, as in the latter case the metal of the shaft and bearings is liable to "seize" and make it very difficult afterward to rotate the armature. It is much better to keep the armature

revolving until it is comparatively cool, even if the speed of rotation is very slow.

NOISE

274. What may be said regarding noise as indicating defects in direct-current dynamos?

Undue noise in direct-current machines usually results from mechanical rather than from electrical defects. The majority of the causes of noise are in parts that have become loosened, and are rattling or knocking. For example, there may be loose nuts, screws or binding posts that rattle while the machine is in operation, or the bearings may be worn so that the armature shaft runs loosely in them and produces a rattling noise. In the latter case there is a possibility of the armature being so much out of center as to strike the pole faces.

As a rule, undue noise about a generator acts as a warning, indicating that something is wrong. An examination should therefore be made at the first indication of such a defect lest the trouble progress from bad to worse and entirely disable the machine. Loosened parts can best be detected by feeling about the generator, or listening while the machine is running, so as to form an idea as to the location of the cause of the noise. Having located the loosened parts, the remedy consists in tightening them, or if the trouble be due to worn bearings they should be renewed. If, on account of worn bearings, the armature rubs against the pole faces, the bearings should be put in proper condition immediately, lest mechanical defects be caused on the surface of the armature.

275. In what ways may the belt and pulley of a generator be responsible for abnormal noises?

Both the belt and pulley may cause noises by striking against the bearings of the machine. This, however, is easily remedied by mounting the pulley a little further out on the shaft so as to avoid contact between the offending parts. The

belt, if laced or jointed, is liable to cause a pounding noise when the lacing or joint comes in contact with the pulley. As this noise occurs but once during each complete revolution of the belt, the cause may readily be detected from the periodic nature of the sound. The remedy is obvious. An endless belt should always be used with electrical machines.

It sometimes happens that the belt makes a squeaking noise, caused by its slipping on the pulley when the machine is heavily loaded. If the load be reduced, the squeaking will cease. In case the load cannot be reduced, the tightening of the belt may prove beneficial; if this does not remedy matters, a wider pulley and wider belt must be substituted for those in use.

If the pulley is not perfectly balanced, it will cause vibrations of the machine which will produce noise. This defect may be detected by the fact that the intensity of the vibrations varies considerably at different speeds. It may be remedied in the same manner as previously explained in Answer 259 for balancing an armature. It may also be noted here that a poorly balanced armature will cause vibrations of the generator, and therefore noise, in precisely the same way as does a poorly balanced pulley.

276. What parts of a generator are liable to produce a singing noise?

Carbon brushes, if not given sufficient slant from the surface of the commutator, or if too hard or gritty, will sing. The commutator, if sticky or not sufficiently smooth, will cause the brushes to produce a similar noise. If the plates of a laminated field or armature core are loose, or if one of them projects slightly beyond its neighbors, a singing noise will result, and a piece of paper or a layer of insulation partly loose will also produce a similar sound.

RULES FOR OPERATION

277. Give directions for starting a direct-current generator.

The generator must first be brought up to its full speed; the field circuit should then be closed, and the adjustable resistance in this circuit slowly cut out until there is not more than one-fourth of the rheostat left in. If the generator pilot lamp does not glow, the brush rocker-arm should be shifted back and forth around the commutator, for the brushes may not be exactly in the right position. It is advisable to move them slowly back and forth through a large angle, and as soon as the generator pilot lamp becomes yellow the rheostat arm should be moved backward slightly, this being kept up until the lamp ceases to increase in brilliancy. Then the rheostat should be manipulated to get the rated voltage. If the machine refuses to pick up, all the connections should be investigated to see that they are clean and tight, after which the operation of shifting the brushes may be repeated.

If the machine still fails to generate, the entire resistance in the field rheostat should be cut out, and lest there be a poor connection in the outer part of the shunt circuit, the shunt field coils should be connected directly across the main terminals or leads. If the brushes be then moved back and forth over the commutator, the machine will generate, unless there is something radically wrong. If the dynamo be series-wound, its field may possibly be excited by temporarily short-circuiting the main leads, care being taken to provide a means of immediately breaking the circuit, or interposing resistance, as the machine picks up. If this precaution is not taken, the armature is liable to be burned out.

278. If all of the directions just given fail to cause a direct-current generator to produce current, what should next be done?

The machine should be shut down and given a close examination. First of all, the brushes should be examined

again to see that they are in the proper position relatively to each other; care should also be taken that the entire contact surface of each brush comes in contact with the commutator. This is an important matter in many small dynamos, and unless given close attention may prove troublesome. All connections being tight, the field windings should be tested with a magneto-set or a battery and electric bell, to see that there is no open-circuit in them. A short-circuit must also be looked for; this defect would not occur within a coil, except it be a partial one, and in such a case the machine would not refuse to generate. The short-circuit might occur externally, in which case it might be visible, or it might be due to two or more grounds which could be detected by testing for this defect in the usual way.

The machine should then be given another trial, and if it still will not generate, the trouble may be attributed to lack of residual magnetism. This may be tested by a piece of iron held near the pole pieces; if the residual magnetism is weak or absent, there will be little or no attraction of the iron. If the generator is one that has been running regularly, its residual magnetism in some manner may have been destroyed. This may have resulted from a severe jar, or from the magnetism of another machine located nearby.

The remedy for lack of residual magnetism consists in connecting the field coils to another direct-current generator, or a storage battery, and allowing the current to remagnetize the field magnet for a few seconds. Care must be taken, however, to connect the positive pole of the separate source of current to that field terminal of the generator which is afterward to be led to the positive terminal of the machine.

279. In the case of a new direct-current generator, what possible reasons are there in addition to those previously given for the failure of the machine to generate current?

One possibility is that the direction of rotation of the armature may be wrong, or it may be that the relation of the field-winding connection with respect to the polarity of the

brushes is not correct. In either of these cases the machine can be made to generate by using an external source of current to excite the fields, but some experimenting may be necessary to get the connections right. It may be possible to remedy the trouble by reversing the direction of rotation of the armature, or by reversing the connections of either the brushes or the field winding, but not of both the brushes and the field winding, as the results would then be the same as before.

280. Illustrate and describe the usual arrangements of circuits in the armatures of direct-current generators, and give the position and number of brushes that should be used in each case for proper operation.

The ordinary two-pole machine is shown diagrammatically in Fig. 50 at *A*. There are two brushes or groups of brushes placed directly opposite, or 180 degrees apart, on the commutator, opposite the spaces between the poles, and from brush to brush there are two circuits through the armature.

In the four-pole winding, shown diagrammatically at *B* in Fig. 50, four brushes or brush-groups are employed, which are spaced 90 degrees apart. The four brushes or groups form two pairs in which the positive brushes are joined together and the negative brushes are joined together. There are therefore four circuits through the armature, the current dividing among them as represented by arrows.

In the four-pole machine illustrated at *C*, Fig. 50, the armature winding is cross-connected so that instead of four brushes or groups as in *B*, there are two brushes or groups spaced 90 degrees apart, through one of which the entire current generated in the armature passes out and through the other, returns. As indicated by the brushes shown dotted, there may if desired be four brushes or groups employed, spaced 90 degrees apart. They would then be divided into two pairs in which the positive brushes would be joined together, and the negative brushes also joined together as in

B. Whether there be two or four brushes or groups employed, there would be four circuits through the armature.

In the four-pole winding shown at *D* in Fig. 50, the armature winding has only two paths through it, and two brushes, instead of four paths in parallel as in the previous cases. The two brushes are spaced 90 degrees apart, and the armature winding is of the ring type. Although the poles are alternately of north and south polarities, the conductors are

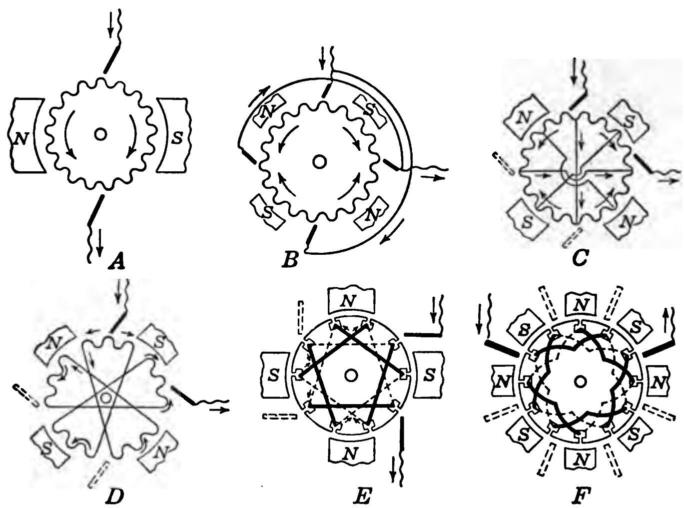


Fig. 50.—Different Arrangements of Circuits in Armatures of Direct-Current Generators, showing also Position and Number of Brushes Necessary.

arranged so that the current flows in a single pair of circuits as was the case in *A*. Since, however, there are twice as many conductors joined in series here as there are in *A*, a smaller number of turns of larger wire may be employed. As in *C*, four brushes may be used here if it be desired to obtain greater brush-commutator contact surface.

A four-pole, drum-wound armature is represented at *E*. The conductors are held in slots in the periphery of the armature core, the end connections on the nearer head being

shown by solid lines and those across the far end by dotted lines. There is only one turn per coil and the winding has only two parallel paths, as in the preceding case, with two brushes spaced 90 degrees apart. Four brushes instead of two may be used.

In the eight-pole, single-turn, two-path drum-wound armature shown at *F* in Fig. 50, two, four, six or eight groups of brushes may be employed. When two groups are used they are spaced 135 degrees apart, but it is usual to have more than two groups in this type of machine on account of the great length of commutator that would be required in order to provide sufficient brush-contact surface with two groups.

TYPICAL MODERN FORMS

281. Are bipolar direct-current generators manufactured now?

Yes; they are still being manufactured for small outputs. For outputs much above two kilowatts, multipolar generators have replaced them.

282. What is meant by a multipolar generator?

A generator having more than two poles; a four-pole, six-pole or eight-pole machine is a multipolar generator.

283. Illustrate and describe a bipolar generator as now manufactured.

Fig. 51 shows a belt-driven bipolar machine, shunt wound, which is made in outputs from $\frac{3}{4}$ to $1\frac{3}{4}$ kilowatts and designed to give 125 or 250 volts. The frame and magnet poles are cast in a single piece of gray iron. Fig. 52 shows the separate parts of the machine. The bearings are supported by arms *c*, *e*, etc., cast solid with the frame. The arms terminate in rings *m*, that are bored out at the same time and to the same diameter as the field-magnet poles *n*, etc., in order to provide seats for the circular bearing housings *b*. The armature *t* can be taken out by removing the four bolts which hold the rear housing. The circular bearing housings can be

rotated to keep the oil wells under the bearings when the machine is mounted on a wall or ceiling.

The bearings are of the self-oiling ring type. Oil brought

Fig. 51.—Westinghouse Bipolar Generator made in Sizes from ¾ to 1¾ Kilowatts.

up from the wells by the rings is distributed by oil grooves to every part of the bearing. Covered openings are provided in the sides of the housings for inspecting the bearings and refilling the oil wells.

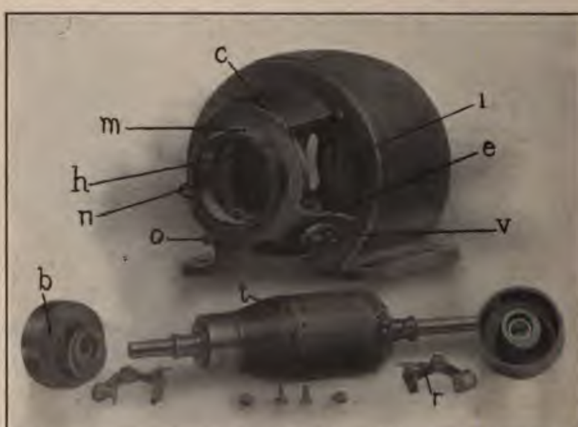


Fig. 52.—Parts of Bipolar Generator shown in Fig. 51.

The field-magnet coils *h* and *l* are composed of cotton-covered wire, machine-wound on forms and then impregnated with insulating compound. They are protected by several

layers of heavy tape and are held in place on the poles by clamping pieces.

The armature is of the drum type with slots to take the winding, which is held in the slots by fiber wedges and by wire bands over the projecting end of the coils; no bands are used over the cores. The core laminations are punched from thin sheet steel and are assembled directly on the shaft and clamped between stiff end plates, one resting against a shoulder on the shaft and the other held by a nut on the shaft.

The commutator is made of hard-drawn copper bars separated by insulating strips of mica. The bars and insulation

Fig. 53.—Westinghouse Multipolar Generator made in Sizes from 2 to 7½ Kilowatts.

are assembled on bushings and clamped between V-shaped rings, from which the bars are insulated by mica; the clamping rings are set up after the commutator has been heated to a high temperature and while it is still hot, so as to hold every bar firmly in place. The complete commutator is pressed onto the shaft and securely pinned to it. The commutator leads are protected by a tough canvas covering and the ends are soldered into slotted projections on the bars.

The rods on which the brush holders are clamped are supported by cast-iron rocker rings which are held rigidly against a machined surface on the front bearing bracket by set

screws. The brush holders *r* are of the simple box type and the brushes are carbon blocks pressed radially against the commutator by flat spiral springs. The terminal wires are brought to binding posts *o* and *v* on the two lower arms supporting the front bearing.

284. Show a multipolar generator for small outputs.

A four-pole direct-current generator for outputs from 2 to 7½ kilowatts at 125 or 250 volts is shown in Figs. 53 and 54,

Fig. 54.—Parts of Multipolar Generator shown in Fig. 53.

the former illustration showing the machine assembled and the latter the separate parts. The magnet poles are cast with the frame and the shunt-field magnet coils are fastened to them as in the bipolar machine. The bearing brackets *a* and *c* are separate castings and are held to the frame by four equally spaced bolts. The armature *m* is built up in much the same way as before, but the stampings forming the core, being larger, are keyed to the shaft; ventilating ducts in the core and openings through the spider afford paths for cooling air currents. The armature coils are wound and shaped before being placed in the slots; and the commutator, instead of being mounted on the shaft, is pressed on an extension of the armature spider and keyed to it. The rocker ring *s* is clamped over a machined seat on the inside of the front

bearing bracket so that the brushes can be moved around the commutator.

The terminal wires *e* and *n* are brought out through an insulating bushing *o* in the side of the frame. As shown at *h*, a bedplate, equipped with belt-tension adjusting screws *l* and *t*, is supplied with the generator.

285. Describe a modern direct-current generator of moderate or large output.

Fig. 55 shows a modern type of direct-connected or engine-type generator having an output of 100 kilowatts at 250 volts

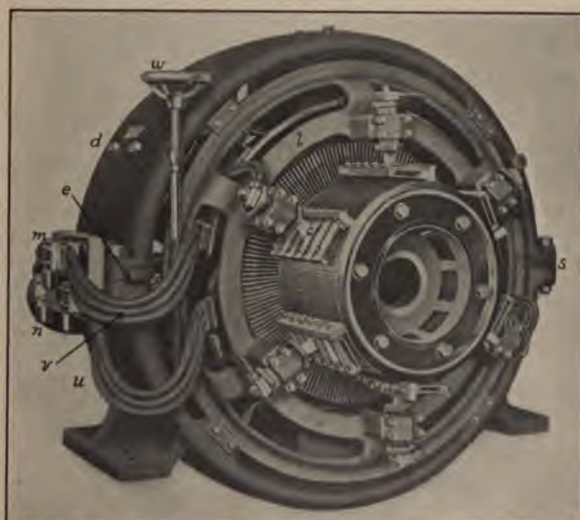


Fig. 55.—Sprague Electric Engine-Type Generator of 100 Kilowatts Output.

when run at a speed of 260 revolutions per minute. Its field-magnet frame is split horizontally at *e* and *s*, the halves being provided with flanges at the joints to facilitate bolting them together. The magnet poles are built up of thin sheets of soft annealed steel and riveted together under pressure, after which they are bolted in place. Two bolts are used for each pole piece and, as shown at *d*, they pass through the yoke

and are fastened by lock washers on the outside; they are threaded and screwed well into the pole pieces, so as to give them a firm hold. The building up of the poles from thin sheets of steel is called laminated construction and is done to prevent overheating by eddy currents, as explained in Answer 270. The bolted-in pole construction allows the removal of any one of the field-magnet poles and its coil

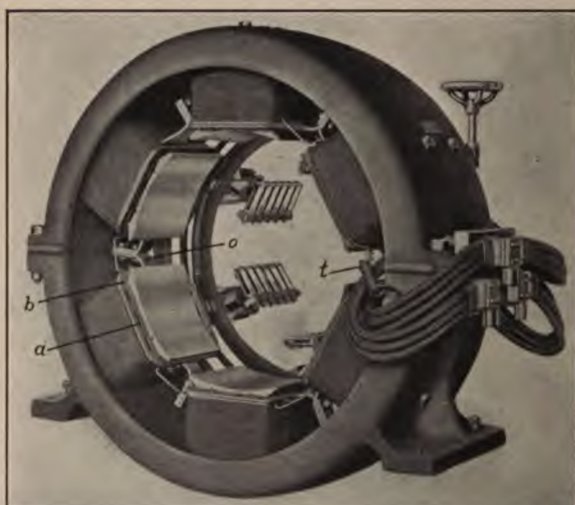


Fig. 56.—Rear View of Generator in Fig. 55, with Armature Removed.

without disturbing any other part of the machine. The magnet pole-tips are spread to give a better commutating field under the pole-tips and the extensions serve to support the field-magnet coils. This construction is clearly shown in Fig. 56, which gives a rear view of the machine with armature removed.

This generator has a compound field winding. The series coils are formed of flat copper strip *o*, which is wound on insulated sheet-iron spools provided with fiber heads *b*, etc. The series coil is wound on first and is separated from the shunt coil, which consists of insulated copper wire *t*, by in-

sulation and a half-inch air space. This air space communicates with the outside air through holes *a*, etc., in the fiber head so as to afford ventilation of the windings and a consequent low operating temperature.

The brush holders *c*, etc., are carried by brackets mounted on a rocker ring *l*, Fig. 55, concentric with and carried on a machined seat on the front end of the field magnet frame. The rocker ring is operated by the hand wheel *w*. Carbon brushes are used, of which there are six on each stud. As

Fig. 57.—Armature of Generator shown in Fig. 55.

there are six poles in all, there are three positive poles and three negative; also three positive sets or studs of brushes and three negative sets or studs. The positive studs are connected to a copper bus ring secured to one of the inner sides of the rocker arm and connecting by means of the insulated copper leads *v* to one of the terminals *m* of the generator. The negative studs are similarly connected to a bus ring on the opposite side of the rocker arm and thence by the leads *u* to the other terminal *n*.

The armature, shown separately in Fig. 57, is built up on a core composed of thin notched punchings of annealed and japanned sheet-steel which are clamped together between cast-iron end plates. The end plates have a projecting flange

for supporting the end winding h of the armature coils, which latter are formed coils embedded in the slots $p\ q$ formed by the alinement of the notches in the armature core punchings. The armature winding is held in place by wooden wedges in the slots $p\ q$ and by the bands f and f. Space plates assembled at the ends and at intervals between the punchings form the openings seen at w, x, etc., necessary for ventilation.

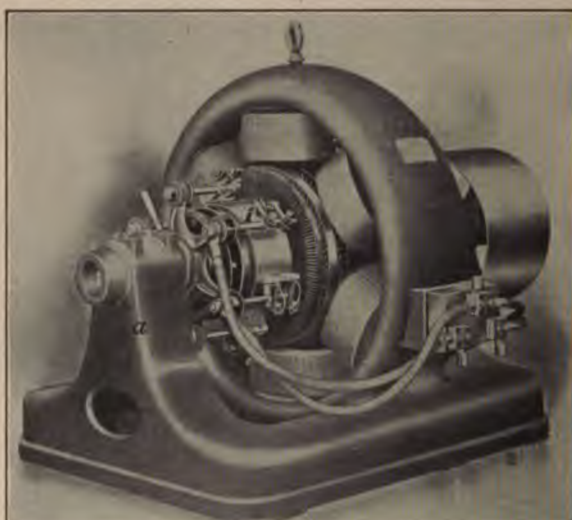


Fig. 58.—Fort Wayne Belted Multipolar Generator made in Sizes from 20 to 90 Kilowatts. Machine has Laminated Pole Pieces cast into the Frame.

The commutator z is clamped by a cast-steel ring g to a cast-iron shell i, which in turn is rigidly supported by the armature spider y.

286. Are not the magnet poles of large direct-current generators sometimes cast into the yoke frames?

Yes; some manufacturers employ this method of construction in all of their machines. Fig. 58 shows a multipolar belted direct-current generator of this construction. The base, field-magnet frame, magnet poles, all of one pedestal

and part of the other pedestal are cast in one piece. The upper part *a* of the pedestal at the commutator side is a separate piece, but with this exception the entire frame is a single casting.

287. **Illustrate and describe in detail the construction of the magnet poles of the generator shown in Fig. 58.**

From Fig. 59, which shows one of the magnet poles before it is cast into the frame, it may be seen that the pole is built

Fig. 59.—Laminated Pole Piece before being Cast-Welded into the Frame.

up of sheets (these are annealed steel) of two different widths *c* and *e*, assembled so as to form the size and shape of the pole pieces. The minute spaces between these laminations and the slight oxidization on the surface of each sheet tend to reduce eddy currents in the pole faces and thereby decrease the iron loss and increase the efficiency of the machine.

The poles are slotted parallel with the shaft, as shown at *n*, to prevent as far as possible the distortion of the magnetic field at heavy loads. The shape of the ends at *m* is such that when the molten metal is poured into the mold for the yoke it grips the bases of the poles firmly and makes a good mechanical and magnetic joint.

288. Are direct-current generators ever built with more than two bearings?

Large direct-current generators designed for belt drive are often built with three bearings. Fig. 60 shows a six-pole

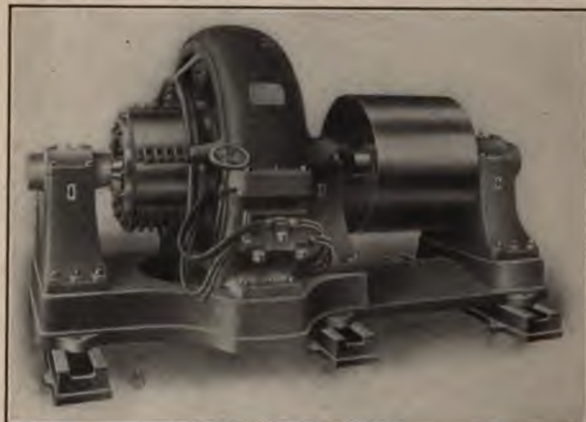


Fig. 60.—Fort Wayne Three-Bearing Multipolar Generator of 200 Kilowatts.

generator of this class built to supply current to a street-railway system. It differs from the generator shown in Fig. 58 in that the bedplate, bearing pedestals and field magnet yoke are separate castings.

289. Illustrate and describe in detail the construction of the armature of the generator shown in Fig. 60.

Fig. 61 shows the armature partly wound; the core *a* is built of mild sheet-steel stampings which are japanned before assembling to reduce the eddy-current losses in the core. These armature-core disks are assembled under heavy pressure and held together by bolts passing through both halves of the armature spider which is keyed to the shaft. Air ducts, *c*, extend from the inside up through the armature windings, and air is forced through them by the motion of the armature.

The armature coils are made of wire or bar copper, according to the capacity of the machine, the latter being employed when large currents are to be carried. These are form wound as shown at *s* to make all coils of the same shape. All coils are wrapped with linen tape, dipped in insulating varnish and baked. The slots of the armature core are also insulated as shown at *e* to afford additional protection to the coils. The coils are held at the ends by tinned-steel band

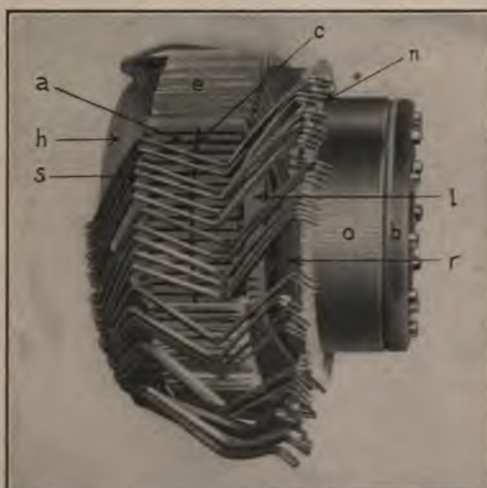


Fig. 61.—Partly Wound Armature of Generator in Fig. 60.

wires beyond the ends of the core, where the cylindrical ribbed flanges *h* and *l* of the spider support the ends of the coils and secure ventilation around the ends of the coils from the interior of the core. Wooden wedges, in notched grooves in the slots below the surface of the core, hold the coils in place throughout the length of the core.

When the armature coils are made of wire, their terminals are soldered directly into the commutator bars or segments, but when formed of bar copper, as in Fig. 61, the terminals *n* of the coils are soldered into flat copper strips which run

down and connect with the commutator bars. Each strip has a clip at the ends to facilitate a soldered connection both with the terminals of the armature coils and with the lugs on the commutator bars. The commutator bars *o* are assembled on a drum mounted on an extension of the armature hub. The bars are securely held on the drum by end flanges at *b* and *r* which clamp over the beveled ends of the bars and draw them together.

Equalizer rings connected to the armature winding at equipotential points are placed between the commutator and the armature core to insure that the brushes of the same polarity be of the same potential.

290. Why is it necessary to use equalizing connections in order that the brushes of the same polarity may be of the same potential?

In the operation of large multipolar direct-current machines with parallel-wound armatures, such as the one being considered, it is difficult to secure exactly the same magnetic strength in all the field-magnet poles. Consequently, the potential generated in the conductors under one pole sometimes exceeds or is less than that generated in the conductors similarly situated under another pole of the same polarity, the result being a slight difference of potential between brushes of similar polarity which causes current, sometimes of considerable magnitude, to flow from one brush to another and from one section of the armature winding to another, attended by annoying and wasteful heating of the conductors and sparking at the brushes.

291. Explain in detail the method used to correct this.

A number of points in the armature winding which should be normally of equal potential are connected by leads or rings outside the winding, through which currents may pass from one section to the others with which it is connected in parallel. These currents circulate through the armature conductors and are alternating in character; they lead or lag with reference to their respective electromotive forces, and thereby

increase or decrease the strength of the field magnet poles automatically so as to produce the necessary balance between them.

292. Do the equalizing connections serve any other purpose?

Yes; they are advantageous in reducing any excess of magnetic pull on one side of the armature, should it get out of center by wear of the bearings, and also prevent the sparking which would be caused under such a condition, by the

Fig. 62.—Crocker-Wheeler Shunt Generator of Small Output with Solid Pole Pieces cast into the Frame.

inequality of field magnet strength due to the difference between the air-gaps on opposite sides of the armature.

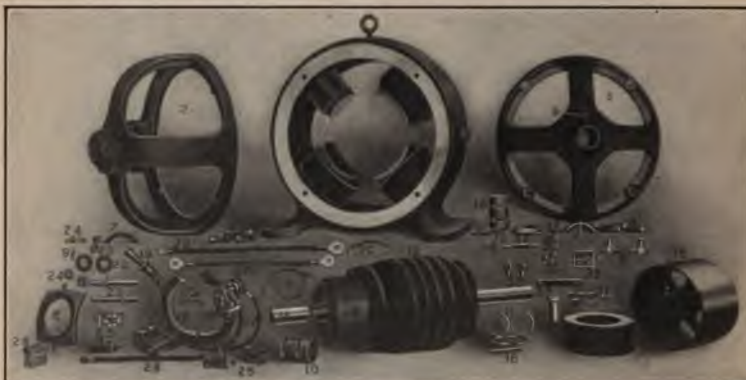
293. Are solid field magnet poles ever cast into the yoke?

Yes; Figs. 62 and 63 show a four-pole shunt-wound direct-current generator embodying this construction.

294. Describe the construction of the generator shown in Figs. 62 and 63.

The frame is of cast iron and the poles are of steel, circular in cross-section, and cast-welded into the frame. The armature core is built up of very thin sheet-steel disks of the form shown in Fig. 63A. These are mounted and keyed directly on the shaft in the smaller sizes and on a cast-iron spider in

the larger sizes. In both cases they are clamped together so that the pressure is applied near the slots in which the armature coils are held. The coils are form-wound, taped and dipped in an insulating varnish; finally they are put in an oven to bake the varnish. There are longitudinal ventilating



1. Magnet Frame.
2. Front Shield.
3. Rear Shield.
4. Shield Cap Screws.
5. Eye Bolt.
6. Pole Shoe with Screws.
7. Oil Hole Cover and Chain.
8. Oil Gages.
9. Journal Screws.
10. Journal Boxes.
11. Oil Rings.
12. Armature, includes 13 and 14.
13. Commutator.
14. Shaft.
15. Pulley.
16. Pulley Key.
17. Field Coils.
18. Rocker, includes 19 and 20.
19. Rocker Handle.
20. Wing Screw.
21. Brush Studs.
22. Insulating Washers.
23. Brush Stud Insulating Bushings.
24. Brush Stud Nuts.
25. Brush Holders.
26. Brushes.
27. Connection Cable and Tips.
28. Terminal Cable and Tips.
29. Shunt Cable and Tips.
30. Shunt Field Connector.
31. Flats with Bolts for Connecting Series Fields.
32. Cable Tips.
33. Porcelain Bushings.
34. Terminal Studs.
35. Washers, plain Brass.
36. Main and Series Labels. Main and Field Labels.
37. Terminal Stud Nuts.
38. Tie.
39. Nameplate and Screws.

Fig. 63.—Designated Parts of the Generator shown in Fig. 62.

holes in both armature core and commutator, and through these, as well as between the commutator leads, air passes freely while the machine is in operation and assists in cooling the armature. The field magnet coils are wound on circular forms, and are heavily insulated and protected by a tough, moisture-proof covering. They are held in place by pole-shoes fastened to the ends of the magnet poles.

The brushes slide in box holders and are pressed against the commutator by adjustable springs. The studs carrying

the brush holders are attached to, but insulated from, a rocker arm by means of which all of the brushes may be shifted simultaneously around the commutator. The armature shaft is made of machinery steel, ground to size. It is made larger in the journals than at the projecting pulley

Fig. 63A.—Armature Disk or Lamination.

end, so that if worn or damaged from any cause it may be turned down without reducing its diameter below that of the projection. The leads from the field coils and brush holders are connected to the inner ends of brass studs which pass through the magnet frame and are insulated therefrom by porcelain bushings. Although the dynamo selected for illustration is shunt-wound, this type of machine is also built either series- or compound-wound.

295. Illustrate and describe a large size direct-current generator built for direct connection with the prime mover.

Fig. 64 shows a generator of this kind built to give 600 kilowatts at 250 volts when run at a speed of 80 revolutions per minute.

The magnet frame *a* is of cast iron and is split horizontally,

the two halves being alined by dowel pins and held together by bolts *c*, *e*, etc. The lower half of the field magnet frame is provided with feet drilled to receive the holding-down bolts and provided with leveling screws for adjusting the position of the magnet frame. The poles are of steel, cast-welded into the frame. Each pole is fitted with a cast-iron remov-

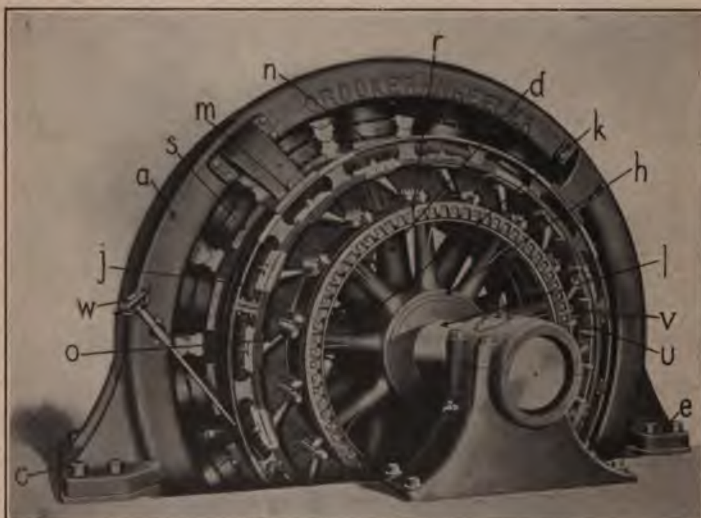


Fig. 64.—Large Engine-Type Generator—600 Kilowatts—Built by the Crocker-Wheeler Company.

able shoe *s*, which distributes the magnetic flux over the armature surface and serves also to retain the magnet coils in position. The air gap or clearance between the armature and pole faces is relatively large to reduce the bad effects resulting from a slight displacement of the armature from its true center.

The machine is compound-wound and the magnet coils are separated from each other and the frame by spacers *n*, to provide free circulation of air between and around the coils. The series coils are wound of copper strip, connections between them being made by interleaving the multiple strips.

The arms *d*, attached to the hub *k*, support the toothed laminations of steel which form the armature core, and there are ventilating ducts in the core and end flanges. The armature conductors consist of flat copper ribbon, heavily insulated and retained in the slots by means of wedges. The commutator spider *h* is mounted on an extension of the armature spider and is therefore independent of the shaft *l*. A sectional clamping ring *r* permits removing a few bars of the commutator without disturbing the others.

The cast-iron rocker ring *j* is rigidly supported at *m*, etc., from the magnet frame and has a tangential screw and hand wheel *w* for shifting simultaneously the position of all brushes. Each set of brush holders is supported on a bracket *o* clamped to the rocker ring, and insulated from it. All the positive brush holders are connected to a copper bus ring *u*, mounted on one side of the rocker ring, and all the negative brush holders are similarly connected to a similar ring *v* on the other side of the rocker ring.

296. Is there any other special form of direct-current generator besides those previously described?

Yes; there is a three-wire generator that differs considerably from those already shown, which are all two-wire generators intended to supply current to two wires—one positive and one negative. A three-wire generator is intended to supply current over short distances to a low-voltage three-wire system of distribution and is used principally in office buildings, machine shops, stores, manufacturing establishments and in large institutions where both lamps and motors must be operated on the same circuit. It is preferable over a two-wire generator system for this purpose on account of the saving in the cost of copper wire for the distributing circuit.

297. Describe the three-wire system of distribution.

The principles of the three-wire system can best be explained by reference to Fig. 65, which shows a diagram of

this system employing two two-wire generators *m* and *h*, each of a voltage equal to one-half the maximum line voltage. If each of the generators supplies 110 volts, the two in series furnish 220 volts across the two outside wires *a* and *c*, while between the middle wire *e* connected to the junction of the two machines and either of the outside wires there is 110 volts. Both 110-volt lamps and fan motors, and 220-volt power motors, may be connected as shown and operated

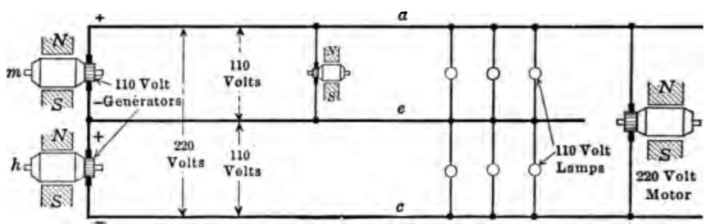


Fig. 65.—Diagram of a Three-Wire System employing Two Two-Wire Generators.

satisfactorily. If the 110-volt load on each side of the middle wire *e* is the same, the current supplied to this load will go out from the generator *m* on the wire *a*, pass through the 110-volt lamps and motors and return to the generator *h* on the wire *c*, so there will be no current in the middle wire *e*, which is called the neutrál wire. With a difference in load on the two sides, only the extra current will flow through the neutral wire. Owing to the current being transmitted at 220 volts instead of 110 volts there is a saving of copper cost with a given energy loss on the line of nearly two-thirds as compared with the copper cost of a two-wire system of the lower voltage.

A three-wire system of this kind requires the continuous operation of both generators. To obviate this the arrangement shown in Fig. 66 is sometimes used. Here a single two-wire 220-volt generator *m* furnishes the voltage between the outside wires, a small motor-generator balancer set *b* is connected across the outside wires, and the middle or neutral

wire is led from a point between the two units of *b*. The machine of the balancer set on the side having the lighter load operates as a motor and drives the other as a generator. This (for the time being) generator supplies current for the

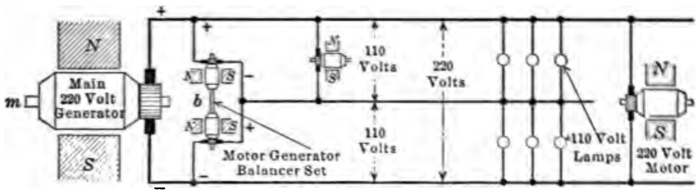


Fig. 66.—Three-Wire System with a Two-Wire Generator and Balancer Set.

excess load on the other side and thus automatically balances the system.

The three-wire generator still further reduces the initial cost and the expense of operating a three-wire system, because there is only one machine to be purchased instead of two or three, and there is less maintenance because there are fewer parts to be cared for. There is also higher efficiency because one machine has smaller losses than any greater number of equal total output, and less floor space is required. The three-wire generator differs from an ordinary two-wire generator in that balance coils are added, and collector rings

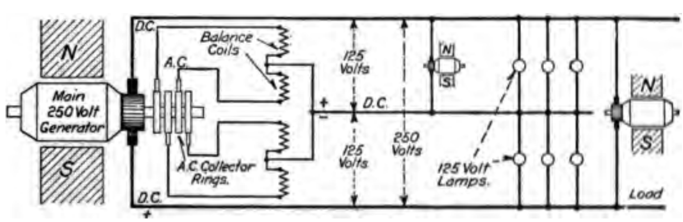


Fig. 67.—Diagram of Three-Wire Generator, showing Balance Coil Connections.

are mounted at one end of the armature, as shown in Fig. 67, to provide suitable connections for them.

298. Illustrate and describe a three-wire generator.

Fig. 68 shows a Westinghouse machine of this type. The balance coils are external to the machine and therefore are not shown in this illustration. Each consists of a single winding on a laminated iron core and is contained in a cast-iron case which may be placed in any convenient location near the generator. Two of these coils are connected in circuit, as shown in Fig. 67, through the four collector rings *c* and the

Fig. 68.—Westinghouse Three-Wire Generator.

copper brushes *b*, Fig. 68. The commutator *a* and the other parts of the machine will be easily recognized as similar to those of any direct-current two-wire generator. A compound field winding is used, and the series field turns are divided into two parts, with one part connected in the positive and the other in the negative line lead, so that the regulation may be preserved at all loads. The machine may be over-compounded to impress an increasing voltage with an in-

creasing load, as is the usual practice with single-voltage machines.

299. Explain how the balance coils operate to produce the two voltages.

For the sake of simplicity, reference will be made to the case of a bipolar generator connected to one balancing coil; this is shown in Fig. 69, and from this diagram it is obvious that the pressure between the neutral n and each commutator

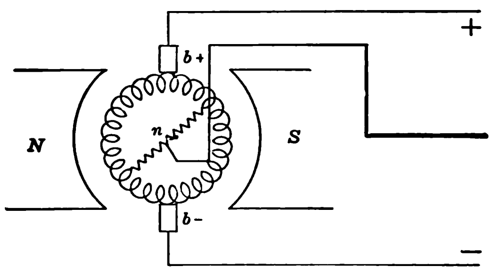


Fig. 69.—Illustrating the Principle of the Balance Coil in Three-Wire Generator.

brush is one-half the total armature voltage. This method of diagrammatical illustration can also be applied to multipolar generators and any required number of balance coils.

The direct-current brushes of the generator are represented by $b+$ and $b-$. The balance coil is permanently connected to opposite points in the armature winding. The neutral wire connects at the point n, the middle point of the balance coil. The winding and connections being symmetrical, it is evident that when the terminals or "tap" points of the balance coil are directly under the brushes, the balance coil is subjected to the full voltage of the armature, and the voltage between the mid-point n and the brush $b+$ is equal to that between n and the brush $b-$, and one-half the total armature voltage.

When the armature has rotated 90 degrees, so that the tap points lie directly under the centers of the magnet poles, the balance coil is subjected to no difference of potential and

the voltage between the middle point *n* and each brush is again one-half the total voltage of the armature, ignoring the drop in the winding of the balance coil, which is so small that it is not important.

In all other positions of the armature the voltage between the point *n* and the brush *b* + is the resultant of half the voltage of the balance coil and that of the armature winding between one tap point and the brush. Correspondingly, the voltage between *n* and *b* — is the resultant of one-half the voltage of the balance coil and that of the armature winding between the other tap point and the brush *b* —. These two are always equal, so that the voltage between *n* and one brush is always equal to that between *n* and the other brush, and *n* is therefore the neutral point and may be so used. The only influence that prevents this arrangement from giving a perfect division of the total voltage between the two branches of the system is the resistance of the windings and circuit connections, and this is so small relatively that it does not cause serious discrepancy under ordinary operating conditions.

300. Why is it necessary to use two balance coils instead of one?

To reduce the fluctuations during each armature cycle, of the resistance and reactance effects of the coils. When the tap points are directly under the brushes, these effects are a maximum, and when the tap points are midway between brushes the effects are minimum. Therefore, when two coils are connected at right angles to each other (in the elementary bipolar case, Fig. 69) each one tends to neutralize the disturbing effects of the other.

301. Is it practicable to operate three-wire generators in parallel?

Yes, they may be operated in parallel, just like ordinary generators, irrespective of the number of poles and speed of each, and they may be regulated for equal voltage in the same manner.

Two-wire and three-wire generators may also be run in parallel. Where there are several generator units, therefore, it is practical to operate one three-wire generator having sufficient capacity to carry the difference between the loads on the two sides of the system, the other machines being of the ordinary type. It is, however, advisable to provide duplicate three-wire units, each of sufficient capacity to provide for the maximum unbalanced condition of the system.

302. Illustrate and describe a typical form of balancer set used in a three-wire system.

Fig. 70 shows a balancer set made by the General Electric Company for use on a three-wire system. The principal

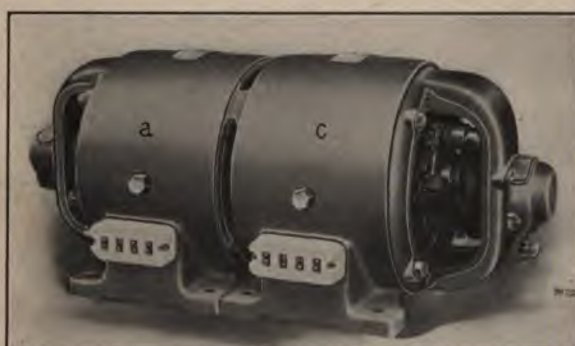


Fig. 70.—Balancer Set made by the General Electric Company.

parts composing the set are shown separately in Fig. 71. The two generator frames *a* and *c*, Fig. 70, are riveted together through spacing blocks, and both armatures *m* and *n*, Fig. 71, are mounted on a common shaft which is strengthened by means of an increase in size between the armatures. A fan *e*, mounted between the armatures, draws air into the space between the two machines to prevent undesirable heating.

303. Is it possible, through any change in construction or arrangement over what has already been shown, to de-

crease the size of a generator for a given output and enable larger overloads to be carried for short periods?

The use of auxiliary or commutating magnet poles tends to produce the results mentioned.

304. Explain the effect of auxiliary magnet poles.

Auxiliary poles between the main field-magnet poles produce a magnetic field of such strength as to reverse the

Fig. 71.—Parts of the Balancer Set in Fig. 70.

current promptly in the armature coils short-circuited during commutation, the brushes remaining in a fixed position. The interference by armature reaction, which ordinarily produces sparking at the brushes, is neutralized because the strength of the auxiliary field produced by the auxiliary poles is always proportional to the load, the coils on these poles being in series with the armature.

305. Illustrate and describe a generator of the auxiliary pole type.

Fig. 72 shows a 1500-kilowatt 550-volt generator containing 12 main field-magnet poles *n*, *s*, etc., and the same number of auxiliary poles, *m*, *m*, etc., located midway between the main field-magnet poles. The poles *m* are wound with insulated copper wire or strips connected in series with the armature

circuit so that the current through the coils around the auxiliary poles varies with the load. The main field winding is usually of the simple shunt kind, but a compound or series winding may be used when service conditions require it. The

Fig. 72.—Large Auxiliary Pole Generator—1500 Kilowatts—Made by the Crocker-Wheeler Company.

generator shown has a compound winding. It is designed to give 550 volts at a speed of 85 revolutions per minute.

306. Do alternating currents possess any advantages over direct currents from an operating standpoint?

Yes. The voltage of an alternating current can be changed or transformed without losing much electrical energy, whereas a direct current cannot. This flexibility makes alternating currents specially advantageous when electrical energy must

be transmitted over long distances, because it permits this energy, generated at a comparatively low voltage, to be readily transformed to a high voltage for transmission over the line and at its destination changed to a low voltage for operating motors, lamps, etc. At the working ends of the line the voltage can thus be sufficiently low to be handled without difficulty, while on the line the high voltage enables the electrical energy to be transmitted at a low current and therefore with small loss and saving in copper conductors.

Other advantages of alternating currents are the simpler construction of alternating-current generators due to the absence of a commutator and the needlessness of using a revolving armature type of machine, the simpler construction of alternating-current motors, and the practicability of locating the generating station outside of or at a distance from built-up communities where the current is to be used and in localities where water power or fuel is readily obtained, where real estate is low and where noise, smoke and vibrations are unobjectionable.

ALTERNATING CURRENTS

PRINCIPLES GOVERNING SINGLE-PHASE CURRENTS

307. Can the variations of a single-phase alternating electromotive force be represented in a diagram?

Yes. The actual variations of the electromotive force developed in an armature coil while it is making one complete

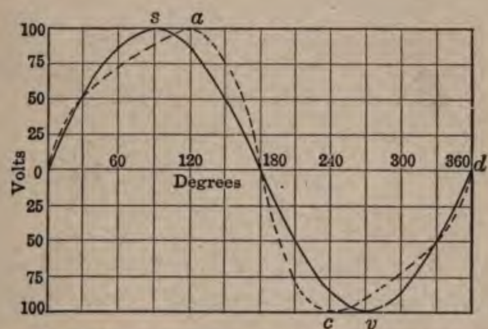


Fig. 73.—Actual and Ideal Curves of Alternating Electromotive Force.

revolution between the field magnets of a two-pole alternating-current generator or alternator depend largely upon the design of the machine, but may be represented by a dotted line curve such as *a c* in Fig. 73. In practice, an alternator always has more than two poles, but the electromotive forces developed in an armature coil, while passing any two of them, will, if plotted, give a curve similar to that marked *a c*. This curve differs from the theoretical electromotive force curve *s v*, Fig. 73, in being less smooth or uniform. The full line curve *s v* is called a "sine" curve, and if drawn to correspond in amplitude to the actual curve, as has been done

in this case, may be used in place of it to simplify the calculations relating to alternating currents and pressures.

308. How is a sine curve produced?

Fig. 74 illustrates the making of a sine curve. Here the same curves and lettering are shown as in Fig. 73. The longest vertical line or "ordinate" *a e* is drawn to a scale which

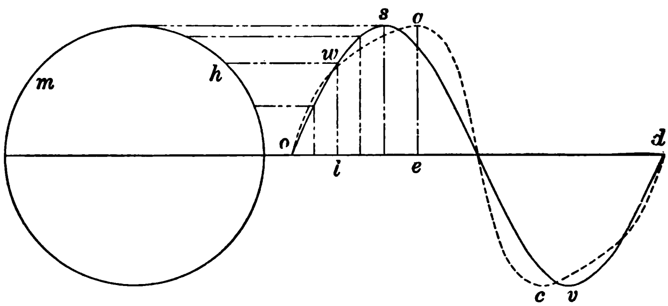


Fig. 74.—Method of Drawing a Sine Curve.

makes its length represent the value of the maximum electromotive force indicated by the curve, and this length is taken as the radius of a circle, *m*, constructed on the prolongation of the line *d o*. By dividing the circumference of the circle *m* into a number of equal parts and the distance *o d* into the same number of equal parts, the circle is unfolded, as it were, upon the line *o d*, thus producing the sine curve *s v*. In order to simplify the drawing, this operation for only a quarter of the circumference and a quarter of the distance *o d* has been shown, these spaces having been divided into four equal parts. The intersections of the broken lines at corresponding points of division as at *h*, *l*, etc., determine the points *w*, etc., which in turn determine the course of the sine curve. This curve, as shown, will be perfectly symmetrical above and below the line *o d*, if correctly determined.

309. How may the actual electromotive force curve of a single-phase alternator be obtained?

Referring first to Fig. 73, it should be noted that the distances along the horizontal or zero line represent degrees,

the entire distance *o d* being divided into 360 degrees, corresponding to the circumference of a circle. As the curves cross the line midway between its extremities this center point is 180 degrees from each end. The ordinates to the curve *a c* represent by their lengths the instantaneous values of electromotive force induced in the armature coil at different points in its travel through one cycle. It is evident that the electromotive forces have zero value at 0, 180 and 360 degrees, and in the sine curve maximum values at 90 and 270 degrees. Under the same conditions these values are the same in each cycle.

In order to obtain the instantaneous values of the electromotive force at different points in the 360 degrees, for determining the actual curve *a c*, the alternator is provided with a metal ring, *a*, Fig. 75, attached to but insulated from the armature shaft *e*, so that *a* will rotate with *e*. This ring should have a projection *n*, and be constructed so that a metal

Fig. 75.—Arrangement for Determining the Instantaneous Values of Electromotive Force.

strip *d* can press continuously against it during the rotation of the armature. An immovable rigid support *m* should also be provided to hold a spring *o* so that the projection *n* touches the spring *o* whenever *n* passes *o*. Once during each complete revolution of the armature, contact will be made and the circuit connected to the strip *d* and the spring *o* closed.

If, then, a sensitive alternating-current voltmeter *v* be joined in circuit as shown, and the wires from *d* and *o* connect respectively with the mains *h* and *l* from the collector rings on the alternator, the voltmeter will indicate at the

instant when contact between d and o is made, the value of the electromotive force between h and l corresponding to the point at which the spring o is placed. By moving the spring o to different positions on m within the space subtended by any one pair of poles as N and S, the corresponding instantaneous voltages may be determined, and if plotted with reference to the positions at which they were obtained will give the actual electromotive force curve for the alternator.

310. By applying the method described in Answer 309 entirely around a 16-pole alternator, how many curves of the shape shown in Fig. 73 would be obtained?

Since the electromotive force curve $a\,c$ shown in Fig. 73 was obtained by taking voltmeter readings past one pair of poles, then with a 16-pole alternator in which there are eight pair of poles, there would be eight complete curves, representing eight cycles per revolution.

311. Has the number of cycles delivered by an alternator any relation to the "frequency"?

Yes, the frequency of an alternator is the number of cycles it delivers per second.

312. How can the frequency of an alternator be calculated?

If f represents the frequency, P the number of magnet poles and s the speed in revolutions per second, then

$$f = \frac{P \times s}{2}.$$

313. Calculate the frequency of a 12-pole alternator running at a speed of 600 revolutions per minute.

According to the problem the number of magnet poles $P = 12$, and the speed of rotation in revolutions per second,

$$s = 600 \div 60 = 10.$$

Substituting these values in the formula, there results

$$f = \frac{12 \times 10}{2} = 60.$$

The frequency is, therefore, sixty cycles per second.

314. What number of poles should an alternator have to give a frequency of 120 cycles when running at a speed of 720 revolutions per minute?

Transposing the factors in the formula to obtain the value of P,

$$P = \frac{2 \times f}{s}.$$

Substituting in this formula the values given in the question, the result is

$$P = \frac{2 \times 120}{720 \div 60} = \frac{240}{12} = 20.$$

The alternator should, therefore, have twenty poles.

315. Give the necessary speed at which a 10-pole alternator should be operated to give 60 cycles per second.

Transposing again the factors, this time to ascertain the value of s,

$$s = \frac{2 \times f}{P}.$$

Substituting in this formula the values given in the question,

$$s = \frac{2 \times 60}{10} = \frac{120}{10} = 12.$$

The alternator must, therefore, run at 12 revolutions per second, or 720 per minute.

316. Between what limits do the frequencies in alternating-current practice vary?

Between 25 and 140 cycles per second, depending upon the type of apparatus being supplied with the current generated.

317. Can the actual variations of a single-phase alternating current be plotted like those of the electromotive force, and do they agree with theoretical conditions?

The actual variations of the current depend upon the conditions of the circuit to which the current is supplied; they may be represented by a dotted line curve similar to the electromotive force curve, such as $r\,n$ in Fig. 76. This curve

differs from the theoretical current curve *e c*, which is a sine curve, in being less uniform and smooth. The curve *e c*, when drawn to correspond in amplitude to the curve *r n*, as in the case of electromotive force, may be used in place of the actual current curve to simplify the calculations.

318. How is the actual current curve of a single-phase alternator obtained?

Referring to Fig. 75, let there be connected between the mains *h* and *l* a known small non-inductive * resistance, such

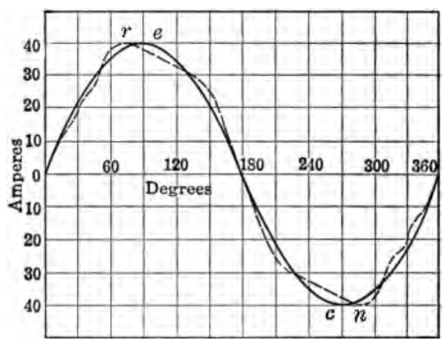


Fig. 76.—Actual and Ideal Curves of Alternating Current.

as that offered by ordinary incandescent lamps. The current through the lamps thus connected will, in accordance with Ohm's law, be proportional to the electromotive force at their terminals. If, therefore, each of the instantaneous values of electromotive force, obtained as explained in Answer 309, be divided by the resistance (in ohms) of the lamps, the results will be the corresponding instantaneous values of the current. If these values be plotted with reference to the positions at which they were obtained, the points thus found will determine the shape of the actual current curve for the alternator under a non-inductive load.

* Non-inductive means devoid of electromagnetic induction.

319. Are the variations in electromotive force and current strength not shown by some other way than that described?

Not in ordinary practice. The *effective* electromotive force is indicated by an instrument termed a " voltmeter " and the *effective* current strength by an " ammeter." These effective values are of chief importance in practical working; they are the geometrical averages of the instantaneous values of the electromotive force and current.

320. What is the relation between the effective electromotive force and the maximum electromotive force shown by a curve like that in Fig. 73?

The effective electromotive force would be 0.7071 of the maximum electromotive force if the alternator produced a sine curve, and as the actual curve is so nearly a sine curve in practice, it is customary to base all calculations on the sine curve. The effective current strength is also 0.7071 of the maximum, theoretically.

321. How is this relation obtained?

If each of the instantaneous values of the electromotive force or current be squared, the squares added together, the sum divided by the number of instantaneous values taken, and the square root of the result extracted, the final result will be the effective value, and it will be found to be equal numerically to the maximum instantaneous value multiplied by 0.7071. Conversely, if the voltmeter reading be divided by 0.7071, the result will be the maximum instantaneous electromotive force of the alternator or circuit. This is also true with respect to the ammeter reading and the maximum current strength.

322. In an ordinary alternating-current circuit is the flow of current impeded in any way?

Practically all electrical circuits contain at some part of them apparatus consisting of coils of wire wound on iron cores. Such apparatus, as was previously explained in

Answer 202, intensifies the effects of electromagnetic induction, producing an electromotive force which opposes the original or impressed electromotive force, and thereby hinders the flow of current. This counter electromotive force, or inductive electromotive force, which is proportional to the square of the number of turns of wire in the apparatus producing it, therefore tends to cause the alternating current to lag behind the impressed electromotive force in its changes of strength; in other words, it causes the current to reach its maximum value each time a little later than the impressed electromotive force attains its maximum.

323. Can this be illustrated by a diagram?

Yes; the relative values of the electromotive force and current throughout one cycle are shown by the curves in Figs. 77

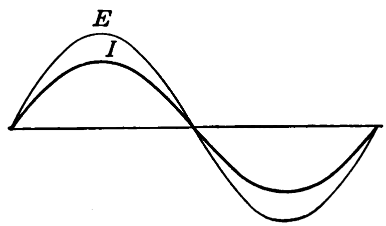


Fig. 77.—Electromotive Force and Current Curves in a Non-Inductive Circuit.

and 78, the former representing the case of an alternating electromotive force and current in a non-inductive circuit, and the latter those in an inductive circuit. In Fig. 77 the current *I* is in phase or in step with the electromotive force *E*, the maximum and minimum values of both current and electromotive force occurring at the same time. In Fig. 78, representing the conditions in an inductive circuit, the current *I* reaches its maximum and minimum values after the electromotive force *E* has reached these respective values. The current in this case, therefore, is not in phase with the electromotive force, but lags behind it by a certain amount which in Fig. 78 is indicated by the distance between ordinates *a* and *o*. The distance from *a* and *o*, measured on the

horizontal line in degrees (the complete cycle of either electromotive force or current being 360 degrees), represents the

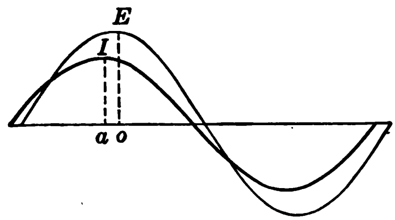


Fig. 78.—Electromotive Force and Current Curves in an Inductive Circuit.

value of the "angle of lag" or difference in phase of current behind electromotive force.

324. **Must other than the impressed electromotive force be considered in the treatment of an inductive circuit?**

Yes, in every inductive circuit there are three electromotive forces to be considered. These are the impressed electromotive force applied to the circuit, the inductive electromotive force which opposes the impressed, and the "working" electromotive force which is the resultant of the impressed and inductive electromotive forces.

325. **Represent graphically the relation which these three electromotive forces bear to each other.**

Referring to Fig. 79, the curve E represents the variations of the impressed electromotive force during one complete

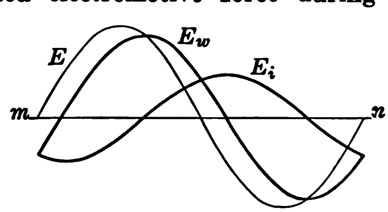


Fig. 79.—Curves of Impressed, Induced and Resultant Electromotive Forces.

cycle, and the curve E_i the variations of the inductive electromotive force, this latter curve lagging behind the current

curve (not shown here) by one-fourth of a cycle or 90 degrees, and being considerably behind the impressed electromotive force curve E.

The inductive electromotive force curve lags 90 degrees behind the current because it is necessarily a maximum when the lines of magnetic force induced by the current are changing most rapidly, and this occurs not when the current is at its maximum, but when it is passing from positive to negative, or from negative to positive—crossing the zero line. When the current is at its maximum value, the inductive electromotive force is zero, so that there is a difference of phase of 90 degrees between them.

The resultant working electromotive force is shown by the curve E_w in Fig. 79. This curve is the resultant of the impressed electromotive force curve E and the inductive electromotive force curve E_i; in other words, any point on the curve E_w is above or below the zero line, a distance equal to the algebraic sum of the distances from the zero line to the curves E and E_i at the corresponding points. When, therefore, the curves E and E_i are both above the zero line, the sum of their ordinates at any point will give the corresponding point for the curve E_w, but where E and E_i are on opposite sides of the zero line the difference between the lengths of their ordinates at any point will be the length of the corresponding ordinate of the curve E_w.

326. How does all this affect the current in the circuit?

It is the resultant electromotive force that determines the current in an inductive circuit, and the current is in phase with that electromotive force,—not with the impressed electromotive force.

327. Give a formula for calculating the value of an alternating current in an inductive circuit.

If E = the impressed electromotive force, R = the resistance of the circuit in ohms, f = the frequency of the electromotive force, L = the inductance of the circuit in millihenrys and I = strength of current in amperes, then the formula is

$$I = \frac{E}{\sqrt{R^2 + X^2}}.$$

In the above equation, $X = 6.2832 \times f \times L$.

328. Is this also the formula for calculating the value of an alternating current in a non-inductive circuit?

It applies to a non-inductive circuit, but in such a circuit the value of L is zero because there is no electromagnetic induction. Consequently the factor X, which includes L, becomes zero, leaving in the denominator simply the $\sqrt{R^2}$ which is equal to R. The formula, therefore, reduces to the direct-current formula $I = \frac{E}{R}$, which was given in Answer **11.**

329. What is the inductance of a circuit?

Its ability to induce a counter electromotive force. The inductance and the electromagnetic induction of a circuit are the same. The unit is the henry, or millihenry, defined in Answer 37.

330. What other units are commonly used in alternating-current work?

Capacity, reactance and impedance. Capacity was defined in Answer 36. Reactance is the combined effect of inductance and frequency of alternations, and is measured in ohms like resistance. It is represented by the letter X, and its relation to inductance and frequency was shown in Answer 327.

331. What is impedance?

The combined effect of resistance and reactance. In the formula given in Answer 327 it is the $\sqrt{R^2 + X^2}$. In alternating-current work it bears the same relation to electromotive force and current that resistance does in direct-current work. Thus, representing impedance by Z, impressed electromotive force by E and strength of current by I, the value of the alternating current in any circuit is found by the equation $I = \frac{E}{Z}$. The impedance is $Z = \frac{E}{I}$ and the electromotive

force required to force a given current through a given impedance is $E = I \times Z$.

The relation between resistance R, reactance X and impedance Z is given by the formulas

$$R = \sqrt{Z^2 - X^2},$$
$$X = \sqrt{Z^2 - R^2},$$
$$Z = \sqrt{R^2 + X^2}.$$

332. Calculate the value of an alternating current having a frequency of 60 cycles in a 1000-volt inductive circuit in which the resistance is 11 ohms, and the inductance 50 henrys.

These figures give the following values to the symbols involved: $E = 1000$; $R = 11$; $L = 0.05$; $f = 60$. From the two latter, X as defined in Answer 327 equals $6.2832 \times 60 \times 0.05 = 18.85$; this is the reactance of the circuit. The impedance Z, which according to the formula in Answer 331 is $\sqrt{R^2 + X^2}$, is therefore

$$\sqrt{11^2 + 18.85^2} = 21.83 \text{ ohms}.$$

The current that 1000 volts would force through this impedance is $\frac{E}{Z}$, as was also explained in Answer 331, which is $\frac{1000}{Z}$ or $\frac{1000}{21.83} = 45.81$ amperes.

333. Determine the impressed electromotive force necessary to force a current of 25 amperes through a circuit in which the reactance measures 6 ohms, and the resistance 14 ohms.

The resistance and reactance being 14 and 6 ohms respectively, the impedance Z, which is $\sqrt{R^2 + X^2}$, will be $\sqrt{14^2 + 6^2} = 15.23$ ohms. As $E = I \times Z$ from the answer to Question 331, the impressed electromotive force required to force 25 amperes through this impedance would be $25 \times 15.23 = 380.75$ volts.

334. If a circuit had a resistance of 5 ohms and a voltage of 1000 produced in it a current of only 125 amperes,

how much inductance would the circuit contain, the frequency being 60 cycles?

The impedance $Z = \frac{E}{I}$ from Answer 331, and in this case must be $1000 \div 125 = 8$ ohms. The reactance $X = \sqrt{Z^2 - R^2}$ must be equal to $\sqrt{64 - 25} = 6.245$ ohms. Since $X = 6.2832 \times f \times L$, then $L = X \div 6.2832 \times f$, or $L = \frac{6.245}{6.2832 \times 60}$, which gives 0.016565 millihenry for the inductance.

335. **Then in order to ascertain the inductance of a circuit, it is necessary to determine first the impedance and then the reactance?**

Not strictly necessary, but it is usually desirable to know both; if one desires to calculate the inductance L from a single formula, the following can be used, but it does not save any work over the method just explained:

$$L = \frac{\sqrt{E^2 - (I R)^2}}{6.2832 \times f I}.$$

336. **Show the application of this formula by determining the inductance of a circuit having a resistance of 10 ohms if a current of 5 amperes results from an impressed electromotive force of 60 volts, the frequency of the current being 25 cycles.**

Substituting the given values in the formula there results:

$$L = \frac{\sqrt{60^2 - 50^2}}{6.2832 \times 25 \times 5} = 0.0422 \text{ millihenrys.}$$

The inductance of the circuit under normal working conditions is, therefore, 0.0422 millihenrys.

337. **Can the power expended in an alternating-current circuit be represented graphically?**

Yes. In Fig. 80 the electromotive force is represented by the curve E and the current by the curve I. If the corresponding instantaneous values of electromotive force and current as indicated by the curves E and I be multiplied together

at close intervals, and the values thus obtained be represented by points on the diagram, account being taken of the positive or negative sign of the product so that the positive values may be plotted above and the negative values below the zero line, *m n*, a curve drawn through the points thus obtained will represent the power in the circuit in watts.

The curve *P* in Fig. 80 was plotted in this way. This curve takes into account the effect caused by the current

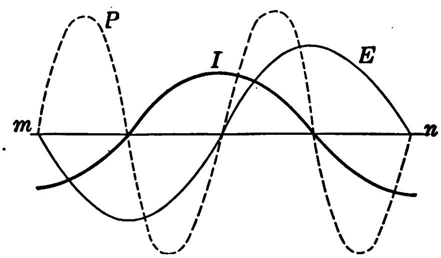


Fig. 80.—Electromotive Force, Current and Power Curves in a Wholly Inductive Circuit.

being out of phase with the electromotive force, whereas if the respective values of voltage and current were measured by a voltmeter and an ammeter, the independent mean effective values of both would be obtained, and their produce would have to be diminished by multiplying by a number called the " power factor " in order to take into account the phase difference between the current and the electromotive force.

338. Explain the conditions represented by the power curve in Fig. 80.

That portion of the power curve lying above the zero line *m n* represents positive power, and is the power sent out by the generator. That portion of the power curve below the zero line represents negative power, or the power returned to the generator and tending to drive it as a motor, on account of inductive apparatus in the circuit. The real power obtained is the difference between the areas enclosed by the positive and negative portions of the power curve. It is of

course desirable to have the positive power in any circuit large in comparison with the negative power, but if the conditions of the circuit be such as to cause a difference of phase of a quarter of a cycle (90 degrees) between the electromotive force and current, as in Fig. 80, the amount of positive power will be equal to that of negative power, so that the actual power in the circuit will be zero. Under such conditions the electromotive force is often spoken of as "wattless," the current as "wattless" and the power as "wattless." At the same time, however, the wires may be carrying their full load current and be unable to carry more on an account of an abnormal rise of temperature in them. The term "useless" is much better than "wattless" for this reason.

339. Under what working conditions will the proportion of useless power in an alternating-current circuit be maximum?

When the circuit contains only electromagnets, condensers or other apparatus having great inductance or "capacity."

340. Under what working conditions will the proportion of useless power in an alternating-current circuit be minimum?

When the circuit contains only incandescent lamps, or other non-inductive and non-condensive apparatus. Under such conditions the current will be in phase with the impressed electromotive force, and the power curve will lie entirely above the zero line. There will then be no "wattless" or useless power, for no power will be returned to the generator.

341. What is the "power factor" of a circuit referred to in Answer 337?

It is the ratio of the actual power to the apparent power or product of the impressed electromotive force and current as measured separately by a voltmeter and an ammeter.

342. Can the power factor of an alternating-current circuit be determined experimentally?

Yes; by measuring simultaneously the impressed electromotive force with a voltmeter, the current with an ammeter and the power with a wattmeter. The voltmeter and ammeter measure respectively the mean effective values of electromotive force and current, as previously explained, and the product of these values gives the apparent power of the circuit. The wattmeter measures the average value of the product of the instantaneous electromotive forces and currents, and thus gives the true power of the circuit. Dividing the value indicated by the wattmeter by the value found for the apparent power gives the power factor of the circuit.

343. Is the true power ever greater than the apparent power?

No. When there is any difference, the true power is always the smaller; consequently the power factor is always less than unity when the current and electromotive force are out of phase.

344. Is the value of the power factor taken into account in the construction of a generator?

No, the generator is designed to carry the full load current and the full load voltage in phase with each other, because it cannot usually be determined in advance what conditions will exist in the circuit to be supplied.

345. What is meant by apparatus having "capacity," as referred to in Answer 339?

If a thoroughly insulated conductor be connected to a generator or any source of electrical energy, a uniform distribution of potential quickly occurs, all parts of the conductor immediately becoming of the same potential as that of the source of supply. To accomplish this result necessitates the transfer of a certain quantity of electricity. The amount of electricity which, under these conditions, can be taken by a body is a measure of its "capacity." The unit of capacity is the farad, as explained in Answer 36.

346. Upon what does the capacity of a conductor depend?

Upon its size and shape; also upon the size, shape, closeness and insulation of neighboring conductors; and upon the nature of the substance (called the " dielectric ") that separates the conductor from neighboring conductors. By increasing the surface of the conductor and diminishing the distance between it and neighboring conductors the capacity is increased.

347. What is a condenser?

An arrangement of conductors for obtaining the greatest possible capacity. One of the commonest forms of condensers consists of a number of sheets of tinfoil separated by thin sheets of mica. The sheets of tinfoil constitute the conductors and the sheets of mica the dielectric.

348. Describe the action of a condenser in an alternating-current circuit.

Fig. 81 represents diagrammatically a condenser, *c*, supplied by an alternator, *a*. When the electromotive force of the

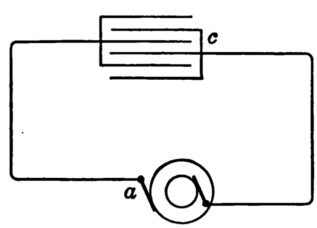


Fig. 81.—Diagram of Alternator in Circuit with Condenser.

alternator rises from zero in the positive direction, current flows into the condenser and " charges " its sheets; as soon as the impressed electromotive force passes the maximum point and begins to diminish, the condenser begins to discharge into the circuit, and when the impressed electromotive force rises in the negative direction the condenser again becomes charged, but in the opposite direction, corresponding with the reversal of the electromotive force. This charging,

discharging and reverse charging and discharging goes on as long as the alternating electromotive force is supplied.

349. What is the effect of a condenser upon the circuit in which it is connected?

The condenser expedites the flow of current, so that the current in the circuit actually attains its maximum and zero values before the impressed electromotive force does. In other words, the current "leads" the electromotive force instead of lagging behind it, as it does in an inductive circuit.

PRINCIPLES GOVERNING POLYPHASE CURRENTS

350. Do polyphase alternating currents differ from single-phase alternating currents?

Not in themselves. A polyphase alternating current is a combination of two or more single-phase currents which differ from each other in phase. Polyphase currents possess the advantage over single-phase currents in that less copper need be used for line wires in the transmission of a given amount of power at a certain loss.

351. Is there more than one kind of polyphase current?

Yes, there are at least two common forms of polyphase currents, one called a "two-phase" current, which comprises two single-phase currents displaced from each other in phase by 90 degrees, and another form called a three-phase current, which comprises three single-phase currents displaced from each other in phase by 120 degrees.

352. Are two-phase and three-phase currents referred to by any other names?

A two-phase current is sometimes called a "quarter-phase" current. A three-phase current has no other common name.

353. Can the variation of a two-phase current be represented graphically?

Yes, the variation of a two-phase current throughout one cycle is shown in Fig. 82.

354. Explain how two-phase currents are obtained in practice.

To produce two-phase currents requires merely a modification of the single-phase alternator previously described. If midway between the armature coils of a single-phase alternator a second similar winding be placed and the two windings be kept separate from each other, the two terminals from each being carried to individual collector rings, there

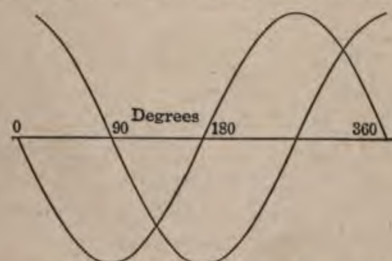


Fig. 82.—One Cycle of a Two-Phase Current.

will be in the working conductors connecting with these collector rings (through brushes) two single-phase currents or a two-phase current, as represented in Fig. 82. This arrangement of armature windings causes the electromotive force induced in the one to reach a maximum 90 degrees, or a quarter of a cycle, ahead of that induced in the other; in other words, when the electromotive force in the one winding is a maximum that in the other winding is a minimum, and *vice versa*.

355. Could not two single-phase alternators be used to produce two-phase currents?

Yes, if the armatures of two single-phase alternators were similarly wound, properly spaced with respect to each other and rigidly held together, two-phase currents could be obtained from them. They should be similarly wound so that the electromotive forces developed by both would be the same when operated at the same speed. The armature of the one alternator must be spaced with respect to that of the other

so that when the coils in the one armature are opposite the field magnet poles, those in the other will be midway between poles; this will produce a phase difference of 90 degrees between them. The armatures of the two alternators would have to be securely coupled together to maintain the proper adjustment between them and to ensure their running at the same speed.

356. Is this method of obtaining two-phase currents used in practice?

Not regularly. It might be used in an emergency, but it is not as efficient or as cheap a method for the purpose as is the use of two windings on a single armature core, and is therefore not used ordinarily.

357. How many working conductors or line wires are used to transmit two-phase currents?

There are two methods of transmitting two-phase currents. In one method four wires are used, as shown in Fig. 83.

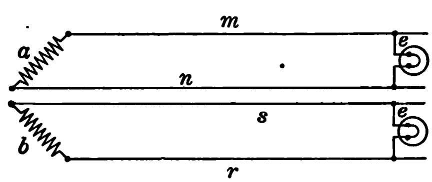


Fig. 83.—Two-Phase, Four-Wire System.

Here *a* represents one of the armature windings of a two-phase alternator and *b* the other armature winding. Each of these windings in the four-wire transmission method is connected to a separate pair of line wires, and from the two independent circuits *m n* and *s r* thus formed, lamps *e*, or other devices, may be operated.

In the second method only three line wires are employed. This arrangement is shown in Fig. 84. The inner terminals of the two armature windings *a* and *b* are joined together, and instead of a line wire connected to each of them, a single

conductor suffices. This single conductor c therefore serves as a common return for the currents in the two outer line wires m and r.

358. What advantage does either method of transmitting two-phase currents possess over the other method?

The three-wire method is preferable to the four-wire method in that, owing to there being but three line wires instead of

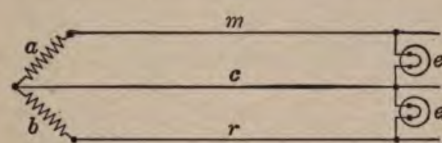


Fig. 84.—Two-Phase, Three-Wire System.

four, less copper wire is required to transmit a given amount of current, but the saving is not sufficient to compensate for the lesser flexibility of this method as compared with the four-wire method.

359. What are the voltages between the line wires of a four-wire two-phase system with respect to those in the armature windings?

Referring to Fig. 83, the voltage between the line wires m n is equal to that developed in the armature winding a less that lost in overcoming the resistance, and the voltage between the iine wires s r is equal to that developed in the armature winding b, less that lost in overcoming the resistance. Inasmuch as the design of the alternator is such that the voltages developed in a and b are equal, the voltage between the line wires m and n is equal to that between the line wires s and r when the resistance losses in the two branches are equal. Since the two circuits are independent of each other, there is no voltage between any line wire of the one branch and any line wire of the other branch; neither is there any voltage between the two armature windings of the alternator.

360. What voltages are there between the line wires of a three-wire two-phase system with respect to those developed in the armature windings?

Referring to Fig. 84, the voltage between the line wires *m* and *c* is the same as that between the line wires *r* and *c*, and each is equal to the voltage developed in either of the armature windings, less that lost in overcoming resistance. The voltage between the line wires *m* and *r* is greater than that between *m* and *c* or between *r* and *c*, but is less than their sum because these voltages differ in phase. The relation is best shown by a diagram. Referring to Fig. 85, the

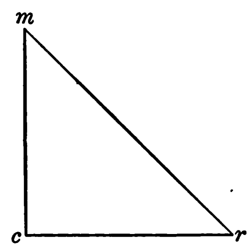


Fig. 85.—Diagram showing the Relation between Voltages in a Two-Phase, Three-Wire System.

line *c m* represents by its length the voltage developed in the armature winding *a*, Fig. 84, and the line *c r* in Fig. 85 represents by its length and position with respect to *c m* the respective value and phase of the voltage developed in the armature winding *b*, Fig. 84. The line joining the points *m* and *r* will therefore represent by its length, as measured by the same scale as the lines *c m* and *c r*, the value of the voltage between the wires *m* and *r*, Fig. 84.

Since the voltages represented by the lines *c m* and *c r* are 90 degrees apart, the angle *m c r* is a right angle, and according to a simple rule in geometry the line *m r* is then 1.414 times the length of either *c m* or *c r*. That is to say, if 1000 volts be developed in either winding of a two-phase alternator, the electromotive force between the outer lines of a

two-phase three-wire system will be $1.414 \times 1000 = 1414$ volts.

361. Are the voltages always the same in both branches of a two-phase system?

Unless the currents in the two outside wires are equal, the system will not be balanced and the voltages in the two branches will be different. Owing to the difficulty of securing proper regulation of voltage in the two branches, it is quite necessary with a lighting load to have whatever lamps are connected equally distributed on the two sides of the central return conductor. But even though the lamps be thus connected up, it is a difficult matter to have those that are burning at any given time equally divided.

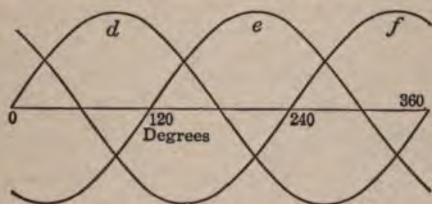


Fig. 86.—One Cycle of a Three-Phase Current.

362. Cannot the circuits be connected to balance automatically?

If the lamps are connected across the outside wires the matter of balance is eliminated, but in this case the output of the alternator will be greatly reduced because its two armature windings will then be acting in series and differing in phase. With a motor load alone, there is no difficulty in maintaining the same voltage in both branches.

363. Can the variation of a three-phase current be represented graphically?

Yes, the variation of a three-phase current throughout one cycle is shown in Fig. 86 by the curves *d*, *e*, *f*. These curves are equally spaced 120 degrees apart, and as in the case of

a two-phase current each of these component currents results from a separate set of coils on the armature.

364. How are three-phase currents obtained in practice?

By dividing the space occupied by the armature coils of an alternator into three equal parts and putting on three equally spaced windings, each composed of the same size wire and the same number of turns as each of the other two windings.

365. How are the armature windings of a three-phase alternator connected with respect to the wires of a transmission line?

The armature windings of a three-phase alternator are joined either in "star" or "mesh" connection with the line wires.

366. Illustrate and describe the star three-phase connection.

The star connection is shown in Fig. 87, in which *a, b* and *c* represent the three windings in the armature of a three-

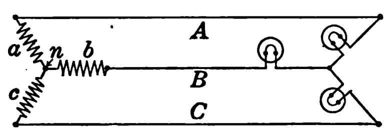


Fig. 87.—Three-Phase Star Connection.

phase alternator, and *A, B* and *C* the wires of the transmission line. Incandescent lamps are connected to the wires as shown. Referring to the armature windings of the alternator, one end of each of these is taken and the three terminals joined together, as shown at *n*, forming a neutral point. The three remaining terminals are connected one to each line wire. With this arrangement, each of the three line wires serves in turn as the outgoing and return wires of the system.

367. What is the relation between the currents in the armature windings of a star-connected three-phase alternator and those in the line wires?

The current in each line wire is exactly the same as that in the armature coil to which that line wire is connected.

368. What relation exists between the voltages developed in the armature windings of a star-connected three-phase alternator and those between the line wires?

The three armature windings *a*, *b* and *c*, Fig. 87, being the same in design, and all three being rotated at the same speed in the field of the alternator, they have equal electromotive forces induced in them. Between the neutral point *n* and each of the three line wires there will, therefore, be equal voltage. The voltage between the line wires, however, is not the same as that developed in any one of the armature windings, nor is it equal to the sum of the voltages developed in any two of them. Referring to Fig. 88, let the lines *n d*,

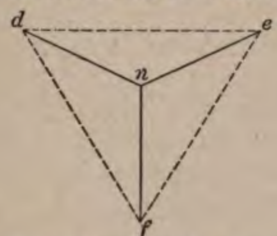


Fig. 88.—Diagram showing the Relation between Voltages in a Three-Phase, Star-Connected System.

n e and *n f* represent by their lengths the voltages in the respective armature windings, *a*, *b*, *c*, and by their directions with respect to each other the phase displacement between these voltages. As the lines are equally distant from each other and all of the same length, lines joining their extremities will be equal in length. If these junction lines be measured by the same scale that was used in drawing the radial lines *n d*, *n e* and *n f*, their length will represent the number of volts between the line wires.

It can easily be proved by geometry that the length of each of the junction lines, such as *d e,* is 1.732 times the length of any one of the radial lines, and it therefore follows that the voltage across any two of the line wires of a three-wire three-phase system is 1.732 times the voltage developed in any one of the armature windings of a star-connected alternator. In other words, a 1000-volt three-phase star-connected alternator will deliver across the line wires, assuming a negligible resistance loss, 1732 volts.

369. Illustrate and describe the mesh three-phase connection.

The mesh connection is shown in Fig. 89, *a, b* and *c,* representing the three windings in the armature of a three-phase

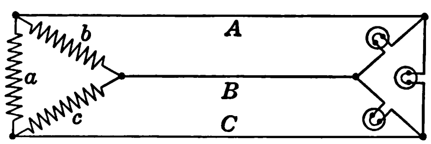


Fig. 89.—Three-Phase Mesh Connection.

alternator, and *A, B* and *C* the wires of the transmission line. Incandescent lamps are connected to the wires as shown. The armature windings of the alternator are connected in a closed circuit, and the line wires make connection with them at the points of junction.

370. What relation exists between the voltages developed in the armature windings of a mesh-connected three-phase alternator and those between the line wires?

All of the three armature windings are the same in design, and all three being rotated at the same speed in the field of the alternator have equal electromotive forces induced in them. As between any two of the line wires there is but one armature winding, the voltage between any two of the line wires is equal to that induced in any one armature winding less the voltage required to overcome the resistance.

371. What is the relation between the current in each of the armature windings of a mesh-connected three-phase alternator and that in each of the line wires?

The same relation exists between the current in each of the armature windings and that in the line wires of the mesh-connected system as that between the voltages developed in each of the armature windings and that across the line wires in a star-connected system. While in the former case resultant electromotive forces were obtained, in this case resultant currents are obtained. Therefore, for each ampere of current in each armature winding of a mesh-connected three-phase alternator, there will be 1.732 amperes of current in each of the line wires.

372. Are there any special advantages possessed by the star and the mesh connections over each other?

Yes; in the star connection there is a lower voltage between the armature windings of the alternator for a given voltage on the line, and therefore less tendency for the armature insulation to become punctured. On the other hand, with the mesh connection, since the voltage in each armature winding is the same as that across the line wires, the line voltage remains more constant and is less affected by disturbing conditions.

373. Would there be any difference in the general design of the armature windings for an alternator whether star connected or mesh connected?

Yes; for a given voltage between the line wires, the armature windings on a star-connected alternator would consist of fewer turns of larger wire than if used in mesh connection.

374. What are the proportions of copper needed in the line wires for transmitting a certain amount of electrical power at a given loss with the different alternating-current systems so far described?

Taking the single-phase alternating-current system as the standard for comparison, and giving it a percentage of 100,

the percentages of copper required for the other systems already described are as follows:

Single-phase system	100 per cent.
Two-phase four-wire system	100 per cent.
Two-phase three-wire system	86 per cent.
Three-phase star-connected system	75 per cent.
Three-phase mesh-connected system	75 per cent.

375. **Are the two-phase and three-phase systems as satisfactory as the single-phase system with respect to practical operation?**

For the supply of lamps they are equally satisfactory. For the operation of motors the two-phase and three-phase systems possess an advantage over the single-phase system because polyphase motors give less difficulty than single-phase motors in starting under load, and they are somewhat lighter in weight.

ALTERNATING-CURRENT GENERATORS

PRINCIPLES GOVERNING THEIR ACTION

376. What are the essential differences between a generator producing alternating current and one producing direct current?

The armature winding is not connected to a commutator, so that the current in the winding is not changed to a direct current; the winding is so arranged that a higher electromotive force is generated; the field magnet has a large number of poles, and its winding is usually supplied with current from a separate source—that is, the field magnet is separately excited.

377. How is the armature winding made to generate a high electromotive force?

By making it of a large number of conductors connected all in series, so that the electromotive forces induced in them are added. In some cases, one-half of the conductors are in series, the winding being divided into two parallel sets of conductors, as in a bipolar direct-current dynamo, except that there are no commutator taps. Fig. 90 is a diagram of an alternating-current generator (called alternator, for short) with a series armature winding, and Fig. 91 illustrates diagrammatically the two-path winding.

378. Is there any other feature that contributes to the high electromotive force of an alternator?

Yes; the revolving part is driven at a much higher peripheral speed than the armature of a direct-current machine.

379. What is the object of connecting the armature winding in two parallel groups, as in Fig. 91?

In order to obtain a lower electromotive force and a larger current capacity. For example, if the machine in Fig. 90

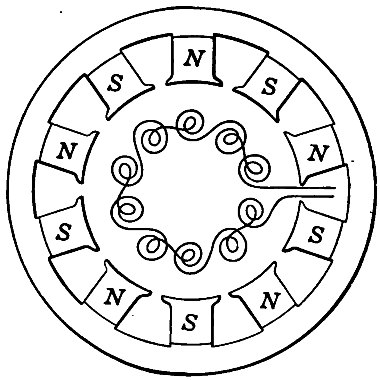


Fig. 90.—Diagram showing General Arrangement of a Series Armature Winding on an Alternator.

produced 2300 volts, and had a capacity of 25 amperes, changing the connections of its armature winding to the two-path arrangement illustrated in Fig. 91 would change the output of the machine to 1150 volts and 50 amperes, without requiring any change in its speed or power.

380. Why is a large number of field-magnet poles employed?

In order to obtain rapid reversals of the electromotive force without using excessive armature speed; the multipolar field magnet also makes the armature more effective in generating electromotive force and reduces the weight of the machine per unit of output.

381. What is the relation between the number of field-magnet poles and the reversal of electromotive force?

The electromotive force reverses every time an armature coil passes a magnet pole; that is, whenever the two " sides " of a coil pass under a pair of magnet poles. Therefore, the

number of reversals per minute is equal to the number of magnet poles multiplied by the revolutions per minute.

382. Why are rapid reversals desirable?

Because the apparatus that receives current from an alternating-current circuit is lighter in weight the higher the

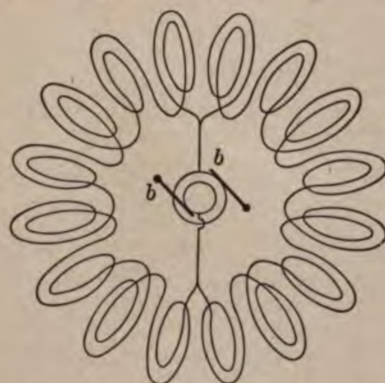


Fig. 91.—Diagram showing General Arrangement of a Parallel Armature Winding on an Alternator.

rate of reversal, excepting incandescent lamps. These, however, require a high rate of current reversal in order not to show the reversals by flickering.

383. How many reversals per minute are employed in practice?

For incandescent lighting alone, from 7200 to 16,000 per minute. When motors are supplied alone, the rate of reversal is from 3000 to 7200. Two reversals are called a "cycle," and it is customary to rate the reversals in "cycles per second." Hence, 3000 reversals per minute would be called "25 cycles per second," 7200 reversals "60 cycles per second," and so on.

384. What do the circles in the center of Fig. 91 represent?

Metal rings, called "collector rings," mounted on the armature shaft. The armature winding is connected to these, and

two brushes, *b b*, held in stationary supports, press against them. This arrangement serves to connect the revolving winding with the external circuit.

385. Why are the rings of different diameters?

They are not, in practice; in the diagram they are shown so in order to prevent confusion. In the actual machine the rings are mounted side by side on blocks of insulating material.

386. How is the armature winding arranged on the core?

There are several ways of arranging it. Fig. 92 shows part of a "developed" winding of the loop or coil type,

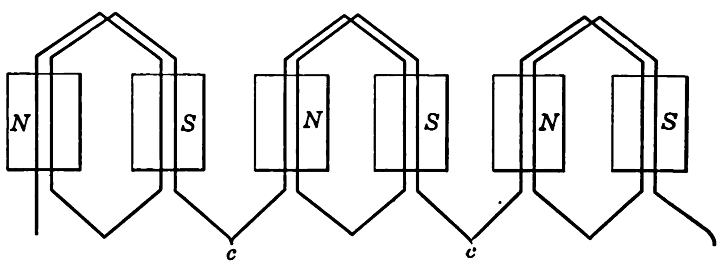


Fig. 92.—Single-Phase Armature Winding of the Loop or Coil Type.

and Fig. 93 shows that part of a zigzag winding similarly "developed." In both cases there are two conductors per magnet pole, but in Fig. 92 the four conductors under each pair of poles, beginning at the left, are wound into a coil, and the several coils are connected at *c*, *c*, etc. (the whole winding is not shown), whereas in Fig. 93 two conductors, one under each of a pair of adjacent magnet poles, constitute an element of the winding, and each element is connected to the one under the next adjacent pair of poles; the connecting points are indicated by *c*, *c*, etc.

387. What is a developed winding?

If an armature winding could be lifted off the core, like a barrel hoop, cut straight across (parallel to the axis of the

armature) and opened out flat, it would be "developed." The diagram of a developed winding, however, also shows

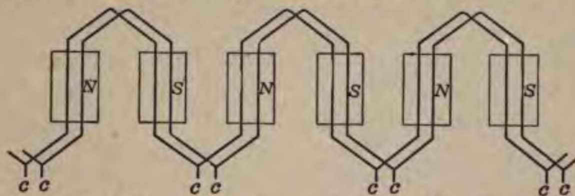


Fig. 93.—Single-Phase Armature Winding of the Zigzag Type.

the relative positions of the field-magnet poles and the winding at some one instant, as in Figs. 92 and 93.

388. When are loop or coil windings used?

When the armature is to give a very high electromotive force, and it is therefore desirable to use coils each containing several turns of wire.

389. When are zigzag windings employed?

When relatively low voltage and large current output is to be obtained; then the winding usually consists of heavy copper bars (which cannot readily be "wound"), formed into open loops and connected up at both ends, as indicated in Fig. 93.

390. What kind of current do the windings in Figs. 90, 91, 92 and 93 deliver?

Single-phase alternating current.

391. How is the winding arranged on a two-phase alternator?

A two-phase armature winding usually consists of two single-phase windings arranged so that the individual loops or coils of the windings are "staggered" with respect to each other. This is illustrated in Fig. 94, where the coils of one winding are shown in solid lines and those of the other in dotted lines.

392. Why are the two windings staggered?

In order that two-phase electromotive forces and currents may be obtained. When one set of coils is opposite the cen-

ters of the magnet poles, and its electromotive force therefore maximum, the other set is midway between poles, and therefore generating no electromotive force.

393. How are the windings connected to the collector rings?

There are two pairs of rings, and the terminals of each

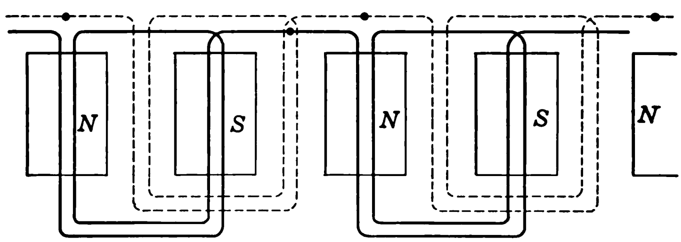


Fig. 94.—Two-Phase Armature Winding.

winding are connected to one pair, as in the case of the single-phase winding.

394. How is a three-phase winding arranged?

There are two ways of arranging it; one using narrow coils, and the other using coils of a width equal to the distance from center to center of adjacent poles, as in the previous cases. There are three distinct sets of coils, each located with respect to the field-magnet poles exactly like a single-phase winding, which it practically is. Fig. 95 shows

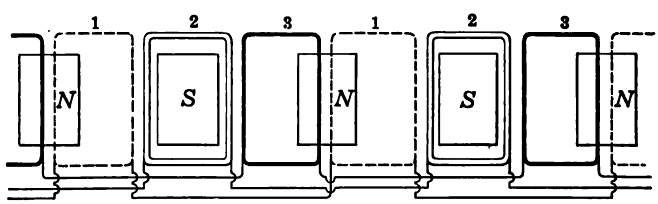


Fig. 95.—Three-Phase Armature Winding with Narrow Coils.

part of a developed three-phase winding with narrow coils, and Fig. 96 is the corresponding diagram for full-pitch coils. One set of coils is represented by the heavy black lines, an-

other by the thin double lines and the coils forming the third set by the dotted lines.

395. What are the relative advantages and disadvantages of the two methods of arranging the three-phase winding?

The advantage of the narrow-coil winding is that the coils do not lap each other, and the winding is therefore less complicated mechanically. It has the disadvantage, however,

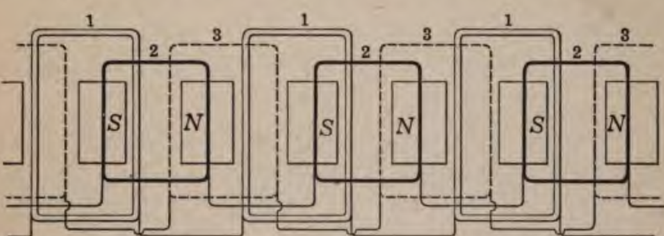


Fig. 96.—Three-Phase Armature Winding with Full Pitch Coils.

that the two sides of each coil do not pass the centers of adjacent magnet poles at the same instant, so that the electromotive force is not as high as in the full-pitch winding, other things being equal; the curve of the electromotive force is also affected, being considerably different from a sine curve, which is the desired shape. The advantage of the full-pitch winding is the elimination of the disadvantage of the narrow-coil winding, and its disadvantage the lapped coils.

MANAGEMENT AND OPERATION

396. Does the management of alternating-current generators differ materially from that of direct-current generators as previously described?

Not when the machines are operated on individual circuits. On account of the peculiar nature of alternating currents, however, and the higher voltages developed in alternators, greater care must be taken to prevent damage to the insulation.

397. How are the field magnets of alternators usually excited?

By direct current passing through a single field winding, and obtained either from a separate direct-current generator or from the alternator itself. In the former case the alternator is "separately excited"; in the latter case it is termed "self-excited."

398. How can direct current be obtained from an alternator?

By mounting on the alternator shaft a small direct-current generator or through the use of a separate winding connected to a commutator on the alternator shaft.

399. Do separately-excited alternators possess any advantages over self-excited alternators?

Yes; when the field current is obtained from a separate source there is better control of the alternating voltage developed.

400. Should an alternating-current generator be belt-driven or direct connected?

Owing to the fluctuations of voltage that are likely to occur from the slipping of the belt, it is preferable to have the alternator direct-connected to its source of power, and the exciter direct-connected to the shaft of the alternator.

401. Are alternators liable to give as much trouble as direct-current generators?

No; they are less liable to give trouble, owing to the absence of commutation (as distinguished from rectification) and the simple, durable construction of the armature. The troubles that do occur generally appear in the field circuit, and for these either the exciter or the rectifier is usually responsible. The exciter, being a direct-current generator, is subject to all the defects previously mentioned for this type of machine. The remedies already given for such trouble are generally applicable in this case.

402. How should an alternator be started?

It must be first brought up to its rated speed; the field should then be excited by closing the switch connecting the exciter with the field windings, the rheostat in the field circuit having all its resistance cut in. By gradually cutting out the resistance of the rheostat, the voltage of the alternator may then be brought up to the normal value. In placing load on the machine, care should be taken to introduce it gradually. On account of the high inductance of the armature winding it is also advisable not to subject the machine to sudden changes in load, as the self-induced electromotive force might puncture the insulation.

403. How should an alternator be stopped?

First, the load must be gradually reduced; under no circumstances should the armature circuit of an alternator carrying full load be opened suddenly, on account of the danger of the high inductive electromotive force puncturing the insulation. Next, the resistance of the rheostat in the field circuit of the alternator should be gradually introduced so as to cut down the alternating voltage developed. When all the resistance in the field rheostat has been introduced, the main switch is opened and the prime mover shut down.

404. Can alternators be operated in parallel?

Yes; if their voltages are equal, their frequencies the same and they be in step with each other when connected up. The case is roughly similar to that of two persons walking side by side; they should be moving at the same speed, have the same length of step and each should be in step with the other.

405. Explain how the conditions for parallel operation are satisfied when it is desired to connect an idle alternator in parallel with one or more machines already in use?

Referring to Fig. 97, suppose the alternator *a* to be running and supplying current through the switch *s* to the circuit *b d*. Also that the alternator *c* is to be put in parallel with *a* for sharing the load within the circuit *b d*. The first

move would be to start up the alternator *c* and run it up almost to proper speed to give the same frequency as the alternator *a*. Maintaining this speed, its field should then be excited until the voltage between its terminals *r* and *v* becomes equal to that between the terminals *m* and *n* of the alternator or alternators already in operation.

Before closing the switch *w*, the alternators must be exactly in phase with each other; that is, their electromotive forces must be at corresponding points of their curves at the same instant. This condition is obtained by increasing the speed of the alternator *c* very gradually until its frequency is almost identical with that of the alternator *a*; then there w'll be, at regular intervals, moments when the electromotive force curves of the alternators will be at identical points. At one of these instants the switch *w* must be closed, thus connecting the two machines *a* and *c* together in parallel on the circuit *b d*. If the switch *w* has been closed at the proper instant, the machines will remain in step and continue to run as smoothly as direct-current generators in parallel.

406. What means are employed in practice to determine when the moments of agreement in the electromotive forces of two alternators occur, so that they may be switched in parallel?

A device called a "synchronism indicator" is used. When the alternators are of comparatively low voltages, such as 110 volts, for example, the synchronism indicator may consist of the simple arrangement of incandescent lamps shown in Fig. 97. Two 110-volt lamps *e e* are connected, each between the corresponding machine terminals which are later to be switched together. When the two alternators are in phase with each other there is no difference of potential between the terminals *m* and *r*, nor between *n* and *v*; consequently, neither of the lamps is lighted. When the alternators are not in phase there is a difference of potential between the terminals *m* and *r* and the same difference between *n* and *v*, so that the lamps are lighted.

The brilliancy of the light emitted indicates the extent to which the alternators are out of phase; thus, when the machines are exactly opposite in phase the lamps will be supplied with 110 volts and give full candle-power, whereas when they come nearer in phase the light will diminish, changing

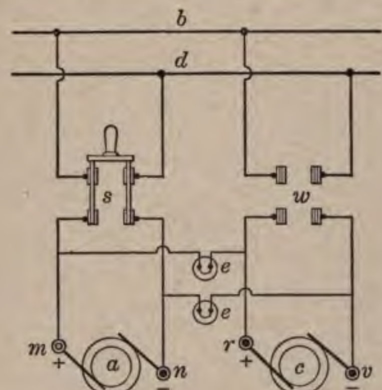


Fig. 97.—Connections for Synchronizing Low-Potential Alternators.

color gradually from a bright yellow to a dull red. When the glow of the lamps disappears entirely, the switch *w* may be closed, connecting the alternators in parallel.

407. With high-pressure alternators, what form of synchronizing device is used?

Transformers are sometimes used in connection with incandescent lamps as shown in Fig. 98. The transformers have their primary windings *a* and *c* connected, the one to the working alternator *m* and the other to the idle alternator *n*. The secondary windings *r* and *s* of the transformers and the incandescent lamps *e e*, are connected in series and in such a way that when the alternators are in phase the currents induced in the transformer secondaries oppose each other. With 110-volt lamps and transformer secondaries giving 110 volts each, the lamps will be dark when the alternators are in phase, and they will be fully lighted when the machines are exactly opposite in phase.

A single transformer having two primary windings and one secondary winding is commonly used for the purpose and is called a synchronizing transformer. In this case the

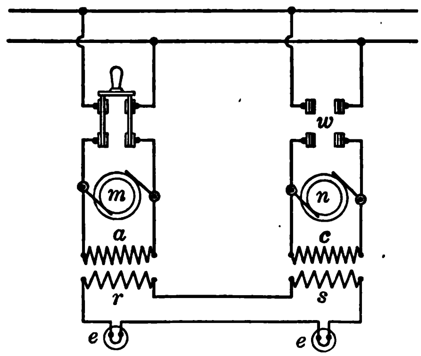


Fig. 98.—Connections for Synchronizing High-Potential Alternators.

primary windings are connected in opposition to each other, so that the lamps in the secondary circuit will be dark when the alternators are in phase.

408. In case the filament in one of the lamps should break during the process of synchronizing, how would this affect matters?

There would be a possibility of closing the switch at the wrong time and thus causing damage. For this reason either a second lamp is connected in parallel with each synchronizing lamp to serve as a check, or else the transformer windings are connected so that when the machines are in phase the lamps light to full brilliancy, and when they are opposite in phase the lamps are dark.

409. Is there no objection to the latter method?

The only objection is that it is somewhat difficult to determine the instant at which the lamps attain their full brilliancy.

410. In case the switch connecting the idle alternator in parallel with the loaded alternator were closed sooner or later than it should be, what damage would be done?

The armatures of the two alternators would partially short-circuit each other, causing abnormal currents to flow between them. These currents might be sufficiently heavy to cause considerable damage before the circuit breakers opened the connecting circuit. The working of the loaded alternator would be seriously disturbed even if the machine were not damaged.

411. After the switch connecting the two alternators in parallel has been closed correctly, what remains to be done?

The load must be equally divided between the machines; this is done by increasing the driving power of the incoming alternator until it assumes its proper share of the load. But little control over the load can be obtained by means of the field rheostats, although these must be kept adjusted so that the normal voltage of the circuit is being developed.

412. How should an alternator operating in parallel with others be disconnected from circuit?

By first decreasing the driving power of the alternator to be disconnected, until the other machines have taken all the load from it, and then opening its main switch.

413. Can alternators be operated together in series?

Yes, if their shafts are rigidly joined together so the machines add their respective electromotive forces. Unless their shafts be connected, the synchronizing tendency which makes it possible to operate alternators so well in parallel causes them to get out of the proper relation with each other when connected in series. It is due to this fact that alternators are very seldom, if ever, operated in series.

TYPICAL MODERN FORMS

414. How may the typical modern forms of alternating-current generators be classified?

In two types: those with a rotating armature and stationary field, and those with a rotating field and stationary armature. The former type is intended for comparatively light load service at low or moderate voltage, such as in

small isolated plants, and the latter type for moderate or heavy loads at moderate or high voltage. The reason for this is obvious because of the greater facility with which the extra insulation necessary for a high-voltage armature winding may be provided when the armature is stationary.

415. Illustrate and describe an alternator with rotating armature and stationary field.

A modern form of this type of alternator is shown in Fig. 99. This is a three-phase 25-kilowatt machine built by the

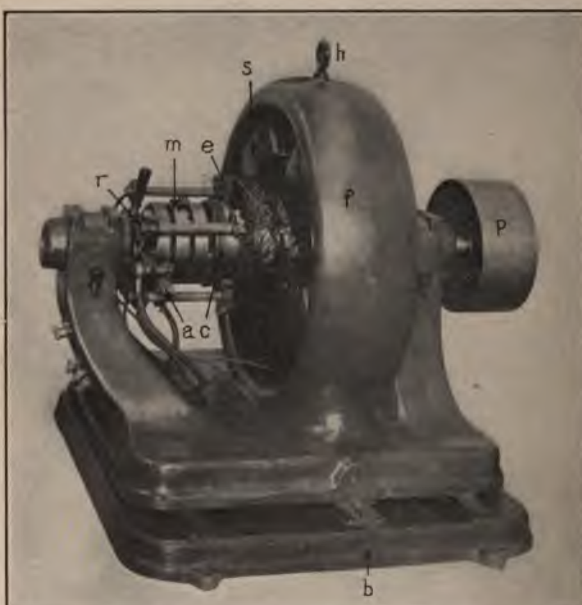


Fig. 99.—Alternator with Rotating Armature and Stationary Field.

General Electric Company, although it can be wound for two-phase 25-kilowatt service. For single-phase service the load is carried by any two of the three leads provided by the machine here illustrated, in which case it is good for 70 per cent. of its three-phase capacity. It is furnished in 120,

240, 480 or 600 volt rating at 60 cycles frequency, and is self-exciting. It is intended to be driven by belt at a speed of 1800 revolutions per minute.

The armature, shown separately in Fig. 100, contains two separate windings: the main generator armature winding, which is connected to the three collector rings at *m;* and the exciter armature winding, which is connected to the commu-

Fig. 100.—Armature of the Alternator in Fig. 99.

tator *c*. Referring to Fig. 99, in which these parts are lettered the same, copper brushes *a*, etc., are used on the collector rings and carbon brushes *e*, etc., on the commutator. Both sets of brushes are mounted on the rocker arm *r*.

The field magnet cores are of laminated construction to prevent eddy current losses and are cast into the frame *f*. The same field magnet coils *s*, etc., serve for both the generator and exciter windings on the armature. The machine rests upon a sliding base *b*, equipped with a screw on the further end for adjustment in tightening the belt on the pulley *p*, and the hook *h* in the top of the frame is for use in lifting the machine.

416. What is the general appearance of a modern alternating-current generator of the rotating field and stationary armature type?

A Crocker-Wheeler three-phase machine of this type is illustrated in Fig. 101. Its capacity is 100 kilowatts at 480 volts and 900 revolutions per minute. The bearings being supported from three-arm bearing frames bolted to the main

frame does away with the necessity for a heavy base and makes the machine very compact.

417. Illustrate and describe the principal parts of the generator shown in Fig. 101.

The frame, armature core and armature winding are stationary. This part, called the stator, is shown separately

Fig. 101.—Alternator with Rotating Field and Stationary Armature.

in Fig. 102. The frame *a* is made of cast iron and is circular in form, a shape which gives strength and rigidity with a minimum amount of metal. It is provided with slots *c* around its circumference for the ventilation of the core *d* within. The feet upon which the machine stands are a part of the frame casting. The armature core *d* is built up of thin flat steel rings or disks with slots punched around the inner periphery, and these are assembled together side by side, so that the slots register with each other and form channels across the core for the reception of the windings. The disks are clamped firmly together, with a spacing plate inserted so as to provide a ventilating duct *e* throughout the core.

The armature or stator winding consists of form-wound coils *b*, which are thoroughly insulated and laid in the slots, which are also insulated; they are firmly held in by means

of wedges. The winding terminates in the three conductors at *m*, by means of which the machine is connected in circuit.

The field is the rotating part and is called the rotor. As shown in Fig. 103, it consists of a solid steel casting forming the field magnet poles and hub in one piece. The field magnet coils *h*, etc., consist of flat copper strip or ribbon wound

Fig. 102.—Stator of Alternator in Fig. 101.

on edge, or of copper wire, according to the requirements of the machine. Each coil is compressed, baked into a compact unit and made to withstand heavy mechanical strain without injury.

The pole shoes *f*, etc., are of forged steel bolted to the ends of the poles. They are shaped to secure uniform distribution of the magnetic flux and also serve to retain the field magnet coils in place.

The field current is conducted to the rotor winding through cast-iron collector rings *r*, etc., and carbon brushes. The collector rings are located one on each side of the rotor, producing a very compact and symmetrical design. Each ring is supported on a cast-iron hub, from which it is thoroughly insulated, and the hub and rotor are mounted on a steel shaft *t*, which extends beyond the bearings at both ends for the driving and the exciter pulleys.

The bearings are of the ring-oiling type and have removable caps to facilitate the removal of the rotor. The journal boxes are of the sealed type so as to be free from oil slinging and are dustproof.

The brush holders are provided with adjustable spring tension and the brushes are self-feeding. The holders are

Fig. 103.—Rotor of the Alternator in Fig. 101.

mounted on brush yokes supported on insulated studs attached to the bearing frames.

Slide rails, as shown in Fig. 101, are furnished with each machine. These fit into planed grooves in the feet of the machine and the belt tension is regulated by means of adjusting screws.

418. What means are employed for exciting the field magnets of the alternator in Fig. 101?

A 125-volt direct-current generator is necessary for this purpose. This may be driven from the exciter pulley on the alternator, or it may be an independently driven machine, or it may be mounted on the alternator itself, as shown in Fig. 104, at *B*, and driven by the alternator shaft.

419. Do not some alternators have their fields arranged to compensate for the voltage drop in the armature winding?

Yes; small single-phase alternators are sometimes provided with two field windings similar to those on compound

direct-current generators, in one of which—the main winding—flows the direct current from the exciter, and the other winding—the compensating winding—is supplied with rectified current from the revolving armature of the alternator which causes the excitation of the field magnet to increase as the load increases. Alternators thus provided with compensated field windings are equipped with a commutator as well as collector rings, and a series transformer, the transformer reducing the voltage to a proper value for the commutator, and the commutator being necessary to rectify or

Fig. 104.—Alternator with Direct-Connected Exciter.

change the alternating current developed in the armature into direct current for the compensating winding. The complete circuits of a single-phase compensated alternator and its exciter are shown in Fig. 105.

420. Describe the construction of the alternator shown in Fig. 106.

In this General Electric machine the exciter E is partially enclosed by the frame of the alternator.

The revolving field and exciter armature are illustrated in Fig. 107, the former at f and the latter at a. Direct current at 125 volts is collected by the brushes b, Fig. 106, pressing

upon the commutator *c*, and is fed into the field magnets *f*, Fig. 107, through brushes pressing upon the collector rings at *r*. In alternators of small output, the field magnets *f* are

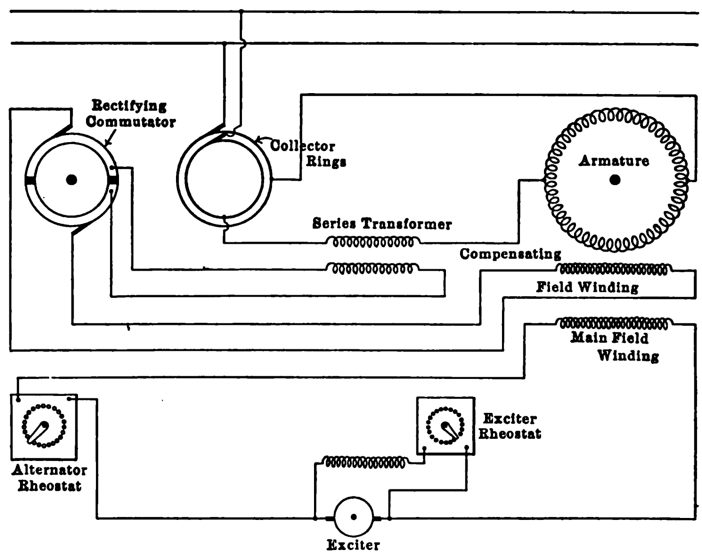


Fig. 105.—Complete Circuits of Single-Phase Compensated Alternator and Its Exciter.

wound with wire as in Fig. 107; whereas in the larger sizes requiring a conductor of greater cross-section to carry the current, copper strip is used, wound on edge and thoroughly insulated between turns and layers.

The stationary armature core is made up of steel sheets, as shown in Fig. 108 at *l*, etc., to reduce hysteresis and eddy current losses to a minimum. These laminations or sheets are stamped in segments, as shown, and are mounted on the inner periphery of the frame, making lap joints to produce a compact magnetic circuit of low reluctance. Each sheet is held in place by means of a dovetail construction, being slipped down on the supporting fingers, *e*, etc. With the spacing plates in position and the clamping rings on, the

completed core has the appearance in Fig. 109, the spacing plates producing the ventilating ducts, t, etc., and the clamping rings being bolted down as shown at m.

Fig. 106.—Alternator with Direct-Connected Exciter mounted partially in Frame.

In Fig. 109, where a portion of the armature core is shown, some of the armature coils are in place. These are form

Fig. 107.—Revolving Field and Exciter Armature of Alternator in Fig. 106.

wound, taped and treated with an impregnating compound to insulate and protect them from mechanical injury, and are

then inserted in the armature slots in an armor *o* of horn fiber. Notches are provided near the outer surface of the

Fig. 108.—The Assembling of the Laminated Stationary Armature Core on Skeleton Frame of Alternator with Rotating Field.

core for the reception of wooden wedges *w* to hold the armature coils in place. A three-phase winding is employed on

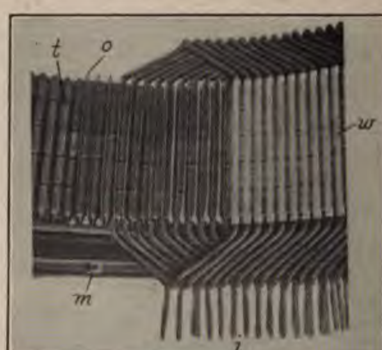


Fig. 109.—Portion of Completed Armature Core with Some Coils in Place.

this machine, the bared terminals *i* of the coils being connected together and thoroughly taped and the three end terminals led outside the machine, as shown at *n* in Fig. 106, for connection with the external circuit. In Fig. 110 a similar

view of the armature core on a larger alternator is shown with the armature coils partly in place.

421. Show how an alternating-current generator is arranged with its exciter when the latter is belt driven from the shaft of the alternator instead of being direct driven by it.

A 100-kilowatt, 2300-volt three-phase Fort Wayne alternator is shown in Fig. 111, arranged to drive its exciter *b*

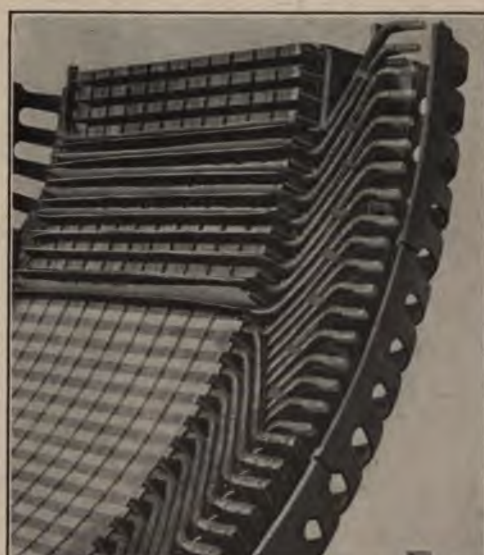


Fig. 110.—Portion of the Armature Core on Large Alternator, partially wired with Form Wound Coils.

by means of a belt *d*. The exciter is a 4-kilowatt direct-current generator delivering 125 volts.

422. Describe the alternator shown in Fig. 111.

The main frame is of cast iron made in two parts *a* and *h*, which are bolted together through the sheet-iron laminations *c* of the armature core. The laminations are in sections to

allow for ventilating ducts and have inwardly projecting teeth, between which the armature winding is embedded, and projections extending out from the usual symmetrical outside circumference. In these latter projections are punched the holes through which the bolts pass, clamping the core and the two halves of the field frame together.

The revolving field magnet of the alternator is provided with eight poles, fitted into a central laminated spider hav-

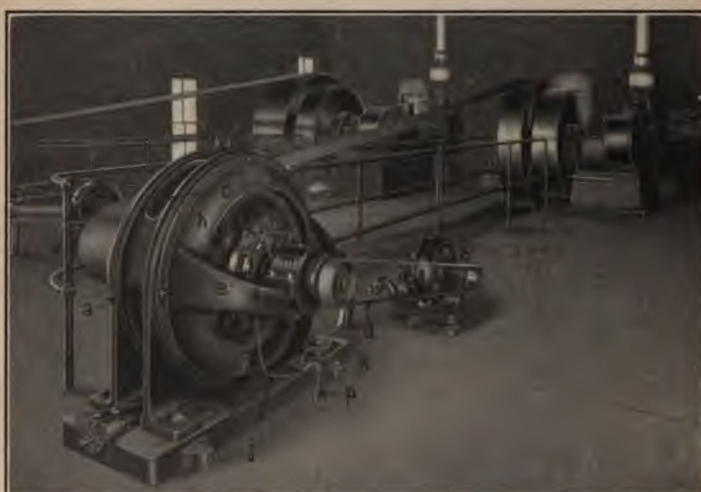


Fig. 111.—Belt-Driven Alternator Belted to Its Exciter.

ing a dovetailed joint and taper keys to hold them in position. After the poles are inserted in the spider, end plates are bolted to each end of the core, closing up the joints. The poles are built up of sheet steel, punched to shape and assembled under pressure between two cast-metal end plates which are riveted together.

The field magnet coils *n*, *s*, etc., are of strip copper, wound edgewise and put in place on the insulated pole before the pole is mounted on the spider. The extended pole tips on

the magnet core hold the coil firmly after the pole is in its position on the spider. The field coils are intended for 125 volts excitation.

The collector rings *e*, etc., through which direct current from the exciter is fed to the revolving field magnet coils, are made of cast iron; each ring is in one piece. Carbon brushes *f* are used. The brush holders are held by brass

Fig. 112.—A 2400-Volt Alternator.

studs insulated from but mounted upon lugs cast on the bearing cap *m*. Each ring has two brushes so that one can be removed for inspection or replacement without interrupting the operation of the machine.

The wires *j* and *k* from the brush holders are led through a pipe *p* under the floor to the switchboard and exciter terminals, and the alternating-current leads from the armature of the alternator also pass through the floor underneath the machine to the switchboard and thence out of the station.

423. Describe the principal features of the form of alternator shown in Fig. 112.

This is a 200-kilowatt, belted three-phase alternator designed to give 2400 volts at 600 revolutions per minute. It is built by the Westinghouse Electric and Manufacturing

Fig. 113.—Frame and Armature Winding of Alternator in Fig. 112.

Company. The frame and armature winding of this type are shown in Fig. 113. The frame is solid and made of cast iron with dovetailed slots into which the laminated core of the stationary armature is built. Openings at *c*, etc., provide air passages for the ventilation of the core. The frame forms no part of the magnetic circuit, its only function being the mechanical support of the armature core, as in the machines previously described.

The armature core *a* is formed by assembling dovetailed punchings of soft sheet steel within the slotted frame. These punchings are separated as shown at *e*, etc., by spacing plates,

leaving a ventilating duct in the core, and are slotted to receive the armature winding *w*. The coils are separately wound, pushed into the slots and afterward connected at the ends. Flexible leads *l* are brought through the frame near the bottom for connection with the line.

The construction of the core of the field magnet, shown in Fig. 114, is somewhat similar to that of the armature, ex-

Fig. 114.—Field Magnet or Rotor of Alternator in Fig. 112.

cept that the laminations are dovetailed as shown at *a*, etc., into a rotating spider *m*, which is also laminated by being built up of thin steel plates firmly riveted together. Ventilating ducts are provided in the core of the field magnet, which register approximately with the corresponding ducts of the armature core.

The field coils *n*, etc., are wound and slipped on the magnet cores before the latter are dovetailed into the spider. Each magnet core is further held in position by two taper steel keys.

The field magnet coils are wound in molds, and made of copper strip bent edgewise. The strip winding is insulated

between turns with asbestos strips and the coils are held together by a few turns of cord.

424. How does a modern type of engine-driven alternating-current generator look?

Fig. 115 shows a Triumph 250-kilowatt, three-phase alternator designed to give 2400 volts. It is intended to be run at a

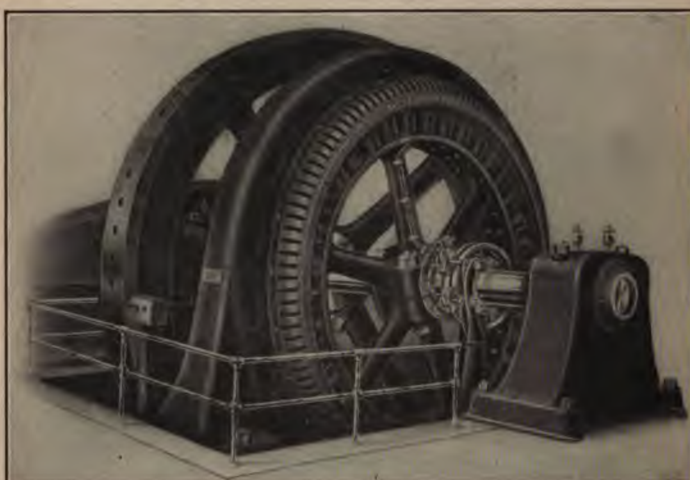


Fig. 115.—Large Engine-Driven Alternator.

comparatively slow speed in comparison with the belt-driven alternators previously considered and this necessitates a comparatively large number of poles; 36 are used.

425. Describe the principal parts of the alternator shown in Fig. 115.

The armature coils can be plainly seen at *c*, in Fig. 116, which shows a portion of the alternator frame. The armature punchings are annealed and varnished to reduce eddy current losses, before being assembled and clamped between the end plates. They are slotted to receive the armature coils, which are form wound, pressed in steam-heated molds so as to

exactly fit the slots, and are interchangeable. Provision is made for sliding the armature to one side to clear the revolving field magnet, thereby exposing the field and armature

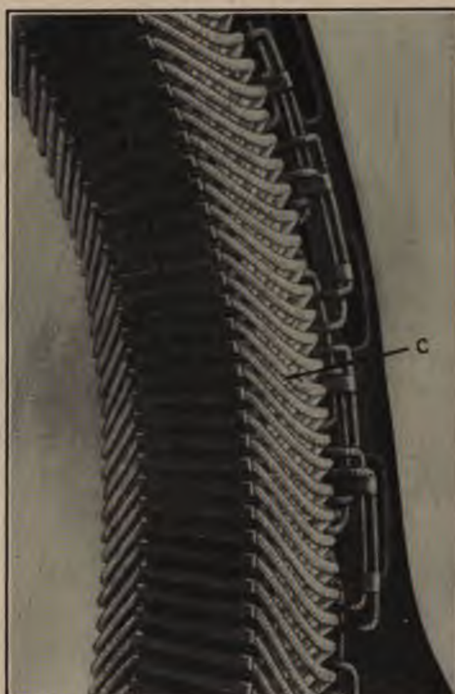


Fig. 116.—Portion of Armature Winding and Frame of Alternator in Fig. 115.

windings and giving good access to them for inspection or repair.

The field-magnet spider, Fig. 117, is cast in two pieces *a* and *b* and bolted together as shown. The low speed permits the magnet cores *n*, *s*, etc., to be bolted to the spider instead of dovetailed into slots. These cores are built up of laminated punchings, annealed and varnished before being clamped between the cast steel end plates. The field magnet

coils are of machine wound copper strip bent on edge, and when insulated are slipped over the magnet cores, which are then bolted to the spider. Low voltage direct current supplied from a separate source is led to the field coils through carbon brushes pressing on the cast iron collector rings *c* and *e*, which are mounted on, but insulated from, the shaft *w*.

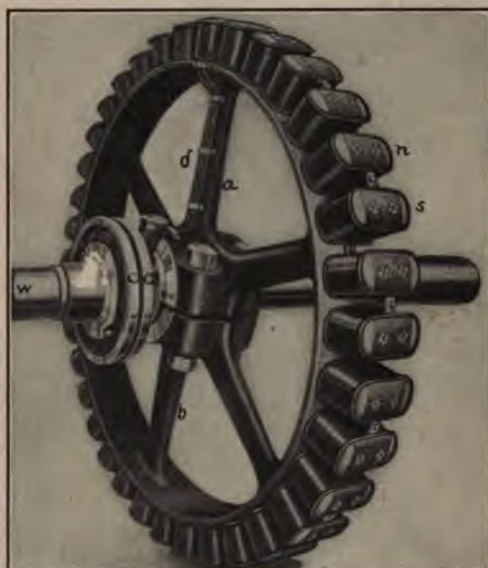


Fig. 117.—Field Magnet of Alternator in Fig. 115.

The conductors leading from the collector rings to the coils are shown at *d*.

For single-phase service the load may be carried by any two leads of the three-phase armature winding, but the kilowatt rating will then be about 70 per cent. of the three-phase value: that is, $250 \times 0.70 = 175$ kilowatts. The machine may also be adapted to two-phase service without change except in the coils and armature punchings, the exciter and all accessories being the same for both.